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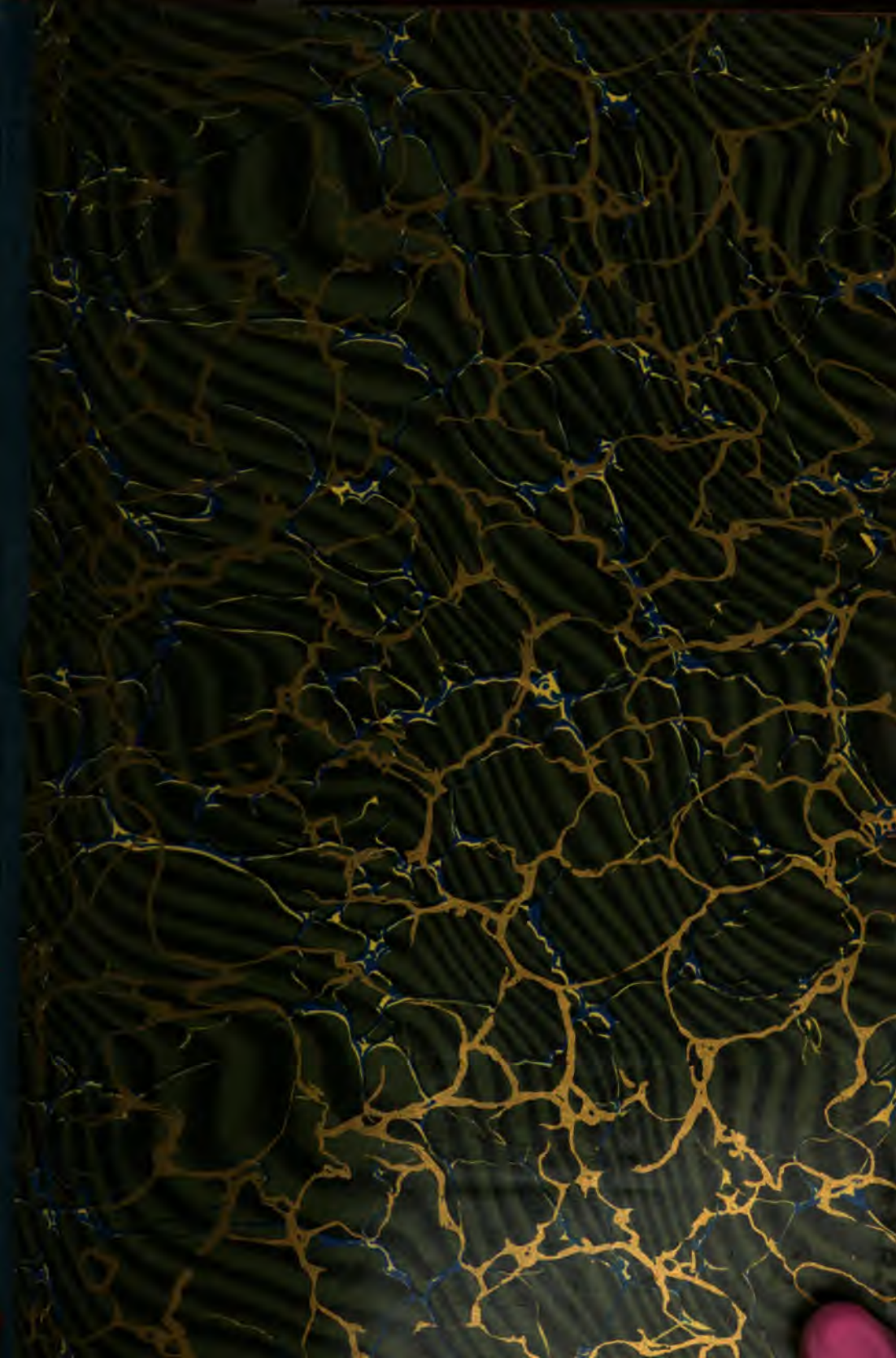
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WORKING CHILLED IRON
GEAR CALCULATIONS
GEAR CUTTING
GRINDING
BENCH, VISE, AND FLOOR WORK
ERECTING
SHOP HINTS
TOOLMAKING
GAUGES AND GAUGE MAKING
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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one or to rise to a higher level in the one he now pursues. Furthermore, he

wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice —together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything

heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

Four of the volumes of this library are devoted to subjects pertaining to shop and foundry practice. The present volume, the second of the series, treats on the following subjects: working chilled iron, gear calculations, gear cutting, grinding, bench and vise work, floor work, erecting, shop hints, toolmaking, gauges, dies, and jigs. All these subjects have been treated very fully and every care has been taken to represent the best modern practice. The papers on Grinding will serve as a guide to those who operate grinding machines and also to manufacturers in selecting wheels best adapted to the work. The papers entitled Bench, Vise, and Floor Work, and Erecting include a thorough treatment on the subject of files and filing, laying out work, and the various types of laying out plates, and the erecting of various classes of machinery. Special attention is called to the papers bearing the titles Toolmaking, Gauges and Gauge Making, Dies and Die Making, and Jigs and Jig Making. Each subject has been treated in a very thorough and exhaustive manner and should prove invaluable to any one interested in toolmaking.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite

the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 37, page 26, will be readily found by looking along the inside edges of the headlines until § 37 is found, and then through § 37 until page 26 is found.

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CONTENTS

	Section	Page
WORKING CHILLED IRON		
Turning Parallel Rolls	7	1
Turning Rolls With Concentric Grooves	7	9
Grinding Chilled Rolls	7	17
Corrugating Rolls	7	20
Planing Chilled-Iron Dies	7	23
GEAR CALCULATIONS		
Gearing	17	1
Spur Gears	17	1
Proportions for Gear-Teeth	17	8
Rules for Spur-Gear Calculations	17	9
Laying Out Teeth	17	17
Involute System	17	18
Cycloidal System	17	26
Bevel Gears	17	33
Worm-Wheels and Worms	17	41
Worm-Wheel Calculations	17	44
Worm Calculations	17	46
GEAR-CUTTING		
Systems and Processes	18	1
Methods and Processes	18	2
Duplication System	18	5
Formed-Cutter Process	18	5
Templet-Planing Process	18	20
Generation System	18	22
Conjugate-Tooth Method	18	22

GRINDING	Section	Page
Introduction	18G	1
Grindstones and Oilstones	18G	2
Grinding Wheels	18G	7
Abrasive Materials	18G	7
Manufacture and Use of Emery Wheels	18G	11
Polishing and Buffing	18G	20
Selection of Grinding Wheels	18G	25
Hand Grinding	18G	27
Hand Surfacing Machines	18G	28
Tool Grinding	18G	32
Hand Tool Grinding	18G	32
Machine Tool Grinding	18G	34
Machine Grinding	18G	41
Grinding Solids of Revolution	18G	42
Advantages of Grinding	19	1
Selection and Use of Grinding Wheel	19	3
External Grinding	19	16
Internal Grinding	19	37
Surface Grinding	19	45
Cutter and Reamer Grinding	19	47
Purpose of Tool Grinding	19	47
Tool Grinding Machine	19	48
Examples of Cutter and Reamer Grinding	19	50
Lapping	19	63
BENCH, VISE, AND FLOOR WORK		
Introduction	20	1
Bench and Vise Work	20	2
Tools and Fixtures Employed	20	2
Chipping	20	19
Files and Filing	20	26
Scrapers and Scraping	21	1
Drills and Drilling	21	6
Broaches and Broaching	21	9
Reamers and Reaming	21	15
Inside Thread Cutting	21	18
Wrenches	21	21

BENCH, VISE, AND FLOOR WORK—*Continued*	*Section*	*Page*
Outside Thread Cutting	21	28
Laying Out Work	21	36
Subdividing Circles	21	42
Laying Out Plates	21	45
Examples of Laying Out	21	53
ERECTING		
Floor Work	22	1
Blocking	22	1
Jack-Screws and Hydraulic Jacks	22	7
Machine Foundations	22	13
Erecting Floor	22	14
Floor Pits	22	19
Use of Erecting Pit	22	25
Driving Fits, Press Fits, and Shrink Fits	22	29
Hoists and Cranes	22	38
Machine Erection	23	1
Lathe Erection	23	1
Planer Erection	23	10
Milling-Machine Erection	23	20
Engine Erection	23	26
Erection of a Horizontal Stationary Engine	23	27
Erection of a Vertical Stationary Engine	23	41
Locomotive Erection	23	46
SHOP HINTS		
Rigging	24	1
Pinch Bars	24	2
Use of Slings	24	3
Use of Lashings	24	4
Chain Hoists	24	5
Splices	24	6
Knots, Bends, and Hitches	24	11
Erection of a Derrick	24	13
Cleaning Work and Castings	24	18

SHOP HINTS—*Continued*	*Section*	*Page*
The Soda Kettle	24	18
Pickling Solutions	24	19
Compressed Air for Cleaning	24	21
Galvanizing	24	21
Tinning	24	26
Filling and Painting Machine Tools	24	28
Notes on Shop Economy	24	28
Cost of Construction	24	28
Time Element in Work	24	30
The Scrap Heap	24	32
Lubricants	24	35
Lubricants for Reducing Friction	24	35
Lubricants for Carrying Away Heat	24	41
Power Transmission	24	45
Belting and Shafting	24	45
Heat Insulation	24	54
Miscellaneous Devices	24	56
Babbitt Metal	24	61
Babbitting	24	62
Useful Information	24	69
TOOLMAKING		
General Tool-Room Work	25	1
Method of Procedure	25	1
Dimensioning Drawings	25	4
Reading Decimals	25	6
Work of the Toolmaker	25	7
Measurements	25	8
Limitations of Toolmaking	25	13
Special Tools Used in Toolmaking	25	14
Cutting Tools and Appliances	25	21
Design and Construction of Taps	25	21
Dies for Thread Cutting	26	1
Reamers	26	11
Counterbores	26	35
Hollow Mills	26	39
Milling Cutters	27	1

TOOLMAKING—*Continued*	*Section*	*Page*
Dividing of the Circle	27	23
Division of Lines	27	34
GAUGES AND GAUGE MAKING		
Classification of Gauges	28	1
Accuracy Attainable in Gauge Work	28	2
Materials Used for Gauges	28	4
Gauge Making	28	6
Plug and Ring Gauges	28	6
Snap Gauges	28	15
Angular Gauges	28	20
Taper Gauges	28	22
Special Gauges	28	42
DIES AND DIE MAKING		
Dies and Punches	29	1
Classification of Dies	29	6
Quality and Design of Dies	29	8
Cutting Dies	29	11
Plain Dies	29	11
Progressive Dies	29	15
Compound Dies	29	18
Laying Out Dies	29	21
Making the Die	29	27
Different Forming Operations	30	1
Dies for Forming	30	2
Bending Dies	30	6
The Drawing Process	30	13
Drawing Dies	30	15
Size of Blanks for Drawing and Forming	30	26
Redrawing Dies	30	28
Coining Process	30	31
JIGS AND JIG MAKING		
Classes and Use of Jigs	31	1
Essential Parts of Jigs	31	2
Types of Jigs	31	2

JIGS AND JIG MAKING—*Continued*	*Section*	*Page*
General Requirements of Jigs	31	3
Jig Details	31	6
Guide Bushings	31	6
Clamping Devices	31	12
Stop-Pins	31	15
Jig Making	31	16
Examples of Jig Design	31	16
Locating Holes	31	26
Locating Holes From a Drawing	31	26
Locating Holes From a Model	31	31
Marking and Recording Jigs	31	33

WORKING CHILLED IRON.

TURNING CHILLED ROLLS.

PARALLEL ROLLS.

1. General Consideration.—In working chilled iron, good results are only possible from good castings; it is necessary, therefore, to see that the castings are free from cracks, blowholes, and dirt, and that the chill is deep enough so that the metal turned off will be of even hardness. In turning any chilled-iron rolls it is necessary to employ special lathes, and a few general rules must be observed in order that the work may be successful: First, the cutting speed must be so slow that the tool will hold its edge until it has done a reasonable amount of work; second, the tools and machine must be of very rigid construction and have a large amount of power, as the working of chilled iron produces severe strains on the machine; third, the tool steel employed must be a high-carbon steel tempered as hard as fire and salt water can make it; fourth, the operator must be patient and be content to turn off fine chips that very much resemble gray hair.

2. Lathes for Turning Parallel Rolls.—Rolls for flouring mills, calendering rolls for paper mills, and rolls for similar purposes, in which a broad flat surface is required, are frequently turned in a special type of lathe, the roll being cast as a hollow cylinder chilled on the outside. This

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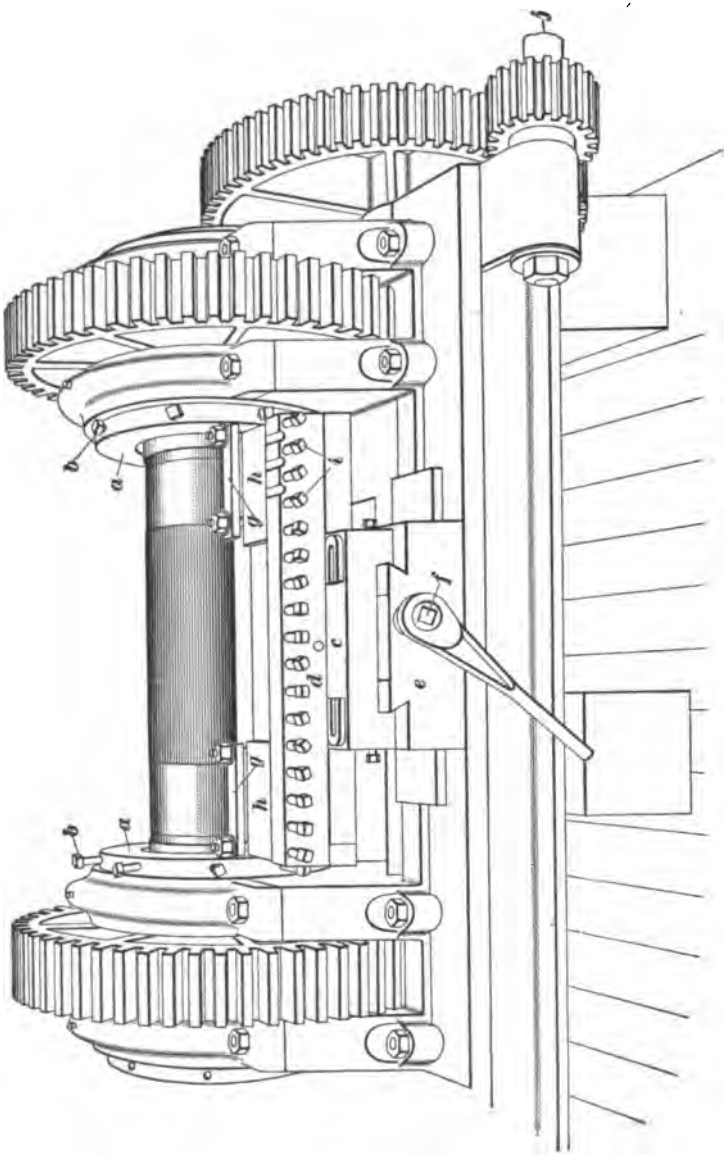


FIG. 1.

cylinder is turned in the lathe and the ends cut off, after which it is bored and fitted on a center carrying the necessary shaft and journals. Then, in the case of flouring-mill and calender rolls, it is ground to a perfect finish while running on its own bearings. Fig. 1 illustrates a common type of roll-turning lathe with the roll in place. In this style, both spindles are made hollow and the roll is introduced through the spindles and held by setscrews *b* passing through the collars *a*. In the style of lathe shown, both spindles are fitted with gears, and the roll is driven from both ends, thus relieving the strain on the lathe.

It will be noticed that this style of lathe is not provided with a carriage having a feed parallel to the length of the lathe, but simply with a broad tool post *d* fitted upon a cross-slide *c* that can be fed along the ways *e* by means of the feed-screw *f*. A set of gearing designed to give the proper speed reduction is placed on the end of the lathe at *j*.

3. Lathes driven from one end only are also made for this work; in this case, the tailstock end of the lathe is made with a hollow spindle through which the roll can be introduced. Some classes of rolls have narrow necks cast on them, and in this case the rolls are held during turning in bearings fitting on the necks in the same manner that the rolling-mill rolls are turned. This will be taken up in connection with the description of the turning of rolling-mill rolls.

4. Holding and Driving the Work.—Ordinarily, in turning 10- or 12-inch rolls that are to be bored and mounted subsequently, the roll is held by means of eight setscrews at each end, these setscrews also acting as drivers. Fig. 2 illustrates the general method of driving. In Fig. 1 can be seen the collar *a* through which the setscrews *b* are passed to hold the work. The same letters have been used for referring to these parts in Fig. 2. The roll *r* is centered and held by means of the setscrews *b*. This method of adjusting and driving the roll enables the workman to center the chilled part very carefully, so that the amount of turning

required will be as little as possible. There is generally about $\frac{1}{8}$ to $\frac{3}{16}$ inch of stock to be turned off from chilled

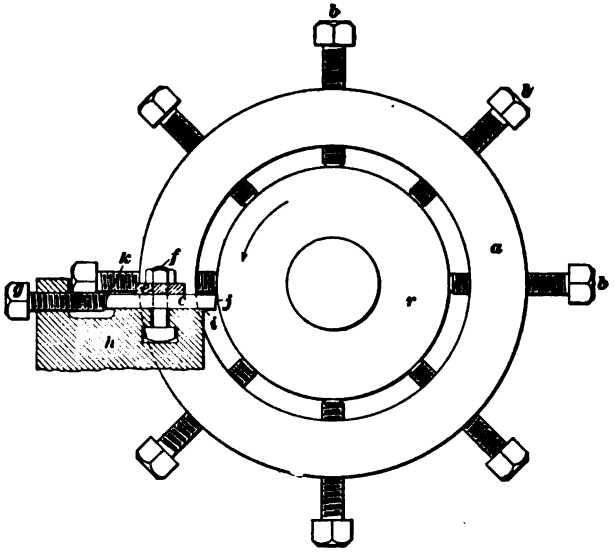


FIG. 2.

rolls, and as the turning process is very slow it is important that the centering be done accurately and carefully.

5. Turning Tools. — The tools commonly employed for turning parallel rolls are flat broad-nosed or wide-faced tools. It is probable that $\frac{1}{2}$ in. × 5 in. × 5 in. is about an average size for straight work. There are on the market several brands of steel made especially for turning rolls. In turning parallel rolls it is common to operate two tools at a time, thus turning 10 inches of the face of the roll. At first thought it might seem best to use one tool 10 inches wide, but it is difficult to harden so wide a tool without its cracking; narrow tools are far less liable to break, and on the whole there is greater economy of steel and less difficulty experienced in adjusting tools when the two 5-inch tools are employed in place of one 10-inch. All tools for turning chilled iron differ radically from those employed on softer

metals, and all the turning is of the nature of scraping, the tools being given but little, if any, clearance. Tools for turning chilled iron are never fed into the work and then traversed along the machine, as is done with softer metals, but are fed straight up to their cut, whether turning a parallel face of a roll or the bottom or the side of a groove.

6. Grinding Turning Tools.—In order to insure a perfectly straight edge on the tool, it should be ground on a grinding machine provided with a carriage or special tool holder. The tool is hardened as hard as fire and salt water can make it and then traversed across the face of an emery wheel to make the face *a b* of the tool concave, as shown in Fig. 3. This leaves two sharp corners *a* and *b*. The tool is first set to use one corner; when this becomes

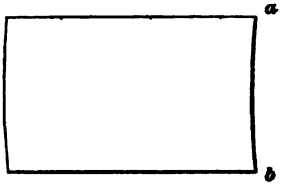


FIG. 3.

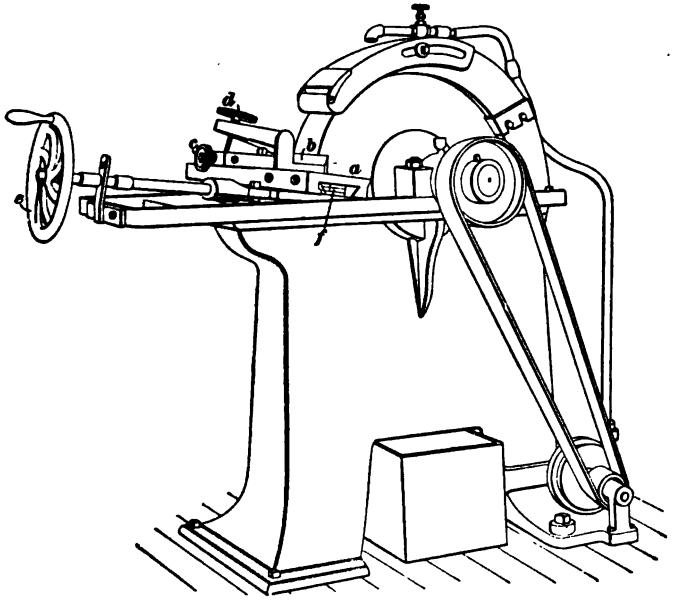


FIG. 4.

dull the tool is turned over and the other corner utilized. Fig. 4 illustrates a wet-grinding emery wheel fitted with a slide *a* upon which the tool can be clamped at *b* and fed back and forth across the face of the emery wheel, the different adjustments being obtained by means of hand wheels *c* and *d*. The carriage is traversed across the face of the emery wheel by means of the hand wheel *e*, which operates a pinion engaging with the rack *f* on the bottom of the carriage *a*. By means of such a device as this the tools can be accurately and quickly ground.

7. Cutting-Off Tools.—Special cutting-off tools are employed for cutting off the ends of the chilled-iron rolls after the bodies have been turned to size. Fig. 5 illustrates one of these tools, which is forged from $\frac{3}{4}'' \times 1\frac{1}{4}''$ steel and tempered by dipping into salt water. The edge of this tool is about $\frac{5}{16}$ inch wide and the corners *a* and *b* are cut off at

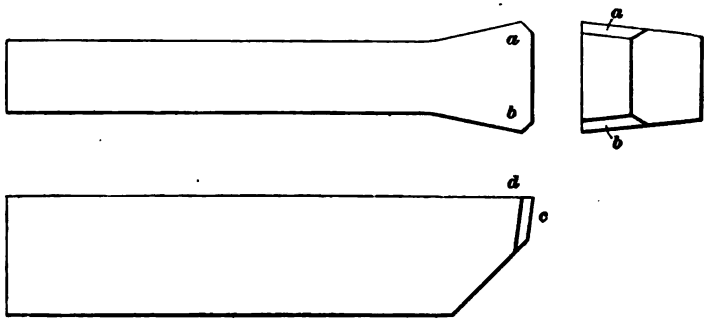


FIG. 5.

an angle of 45°, as shown. Grinding the corners in this manner prevents the breaking of the sharp corners that would otherwise occur. The front face of the tool is given a very little clearance, as shown at *c*. This rarely if ever amounts to more than 5°. This form of cutting-off tool is employed simply for cutting through the chilled iron. After the softer iron at the center of the roll has been encountered, an ordinary cutting-off tool may be substituted for the special one shown.

8. Holding the Tools.—Owing to the great strain to which tools employed for working chilled iron are subject, it is impossible to hold them in any ordinary tool post, and, hence, they must be clamped to the lathe very rigidly. The ordinary methods for holding the tools for turning parallel rolls are clearly shown in Figs. 1 and 2. In Fig. 2 the tool *c* is set on the carriage *h* and clamped down by means of the strap *e*, which is held in position by two bolts *f*. The tool is forced against the rolls by means of a series of setscrews *g*. Care must be taken to see that the front face of the rest is close to the roll, as shown at *i*. The closer this rest is to the roll, the less danger there will be of breaking the front face of the tool. The flat tools employed for this work may be originally $\frac{1}{2}$ in. × 5 in. × 5 in., but they are subsequently ground parallel to one axis only. If the tool is ground on one face only, but two cutting edges can be obtained from one grinding. If the tool is ground on both edges, as, for instance, *j* and *k*, four cutting edges will be obtained. When these have been dulled, the tool is ground again, and each succeeding grinding makes it narrower. Tools can be used until they become so narrow that they can no longer be held by the clamps *e*. In Fig. 1, the clamps can be seen at *g*; in this case very narrow tools are being employed and packing pieces *h* are placed behind them for the setscrews *i* to bear against. The upper edge of the tool *c*, Fig. 2, is set $\frac{1}{4}$ inch below the center of the 10-inch roll. This, together with the concave form of the face, will give the proper amount of clearance. In setting cutting-off tools, they are clamped by means of one or more clamps similar to *e*, Fig. 2, and the back end of the tool is set against a setscrew or a packing piece held by two or more setscrews. In the case of cutting-off tools, it is necessary to have them overhang the front edge of the rest *i*, Fig. 2, to a greater extent than in the case of turning tools, and, consequently, it is necessary to have the tool deeper from the top to the bottom, so that it may be stronger. This is why the cutting-off tool shown in Fig. 5 is made $1\frac{1}{4}$ inches deep, and as the top face *d* comes above the center of the

roll, clearance must be allowed on the face *c*, Fig. 5. After the tools have been clamped in place they are fed to the work by means of the feed-screw *f*, Fig. 1, and are kept parallel with the face of the work by adjusting the setscrews *i*. The shavings resemble very fine needles or gray hair.

9. Cutting Speeds. — The cutting speed depends to some extent on the character of the chilled iron being turned, the character of the steel employed, and the number of machines run by one man. In the case of job work, or where one man has to give all his time to a single machine, it pays to run at a comparatively high speed and sacrifice the tools more rapidly, thus gaining a greater showing for the man's time; but, where it is possible to have matters so arranged that one man can operate five or six roll-turning lathes, a speed of 18 inches per minute is usually considered best, as at this speed the tools will last long enough to do a fair amount of work, and as they remain sharp longer they will produce a better surface. By running a number of machines, a man is able to turn out a good day's work. In some cases, where a limited amount of work is to be done and time is an important factor, work is run as rapidly as 3 feet per minute, but this is probably the maximum speed at which good work can be done on chilled iron.

10. Feed.—As has already been stated, in turning chilled iron a tool is never fed along the length of the work but at right angles to the face being turned; consequently, the motion that corresponds to a feed must be at right angles to the work. When turning rolls, the feeding is usually done by hand at a rate that rarely if ever exceeds $\frac{1}{100}$ inch per revolution. A portion of the surface of the roll corresponding to the faces of the tools in action is turned to the required diameter; the tools are then reset at another place and another part of the surface equal to that already turned is finished.

11. Cutting Off the Ends.—After the face of the roll has been turned to the correct diameter, it is cut off to

the proper length by means of cutting-off tools. The roll is never entirely cut off on the lathe, but is cut down until it has a narrow neck or, in case the roll was cast hollow, a shell about ¼ inch thick about the core; it is then removed from the lathe and iron wedges driven into the cut made by the cutting-off tool to force the end off. In case the roll is to be bored out and mounted on a bushing, the boring is done with ordinary tools in another machine, because of the fact that the central portion is soft.

TURNING ROLLS WITH CONCENTRIC GROOVES.

12. General Consideration.—Rolling-mill rolls are practically all turned with concentric grooves or with concentric rings about them, these rings being made by turning away the stock between so as to leave the rings projecting. Practically all rolling-mill rolls for moderate-sized work are cast in a parallel chill and are chilled to such a depth that the grooves will not turn through into the soft metal. Rolling-mill rolls may be divided into three classes: those made of chilled iron, called *chilled rolls;* those made simply of hard iron cast in a sand mold, called *sand rolls;* and those made of a mixture of cast iron and steel, called *semisteel rolls.* The two latter classes are not so hard as the chilled rolls, and are, therefore, turned in a manner more nearly approaching that employed in the turning of hard castings. We shall here deal simply with the turning of chilled-iron rolls.

13. The Lathe.—The exact form of lathe employed must necessarily depend to a large extent on the size of the rolls operated on. Fig. 6 illustrates a representative type of roll-turning lathe. It will be noticed that the lathe is very powerful, and is provided with double helical gears, so that the pull may be constant and that the teeth of the gears cannot cause hammering or backlash. The lathe is

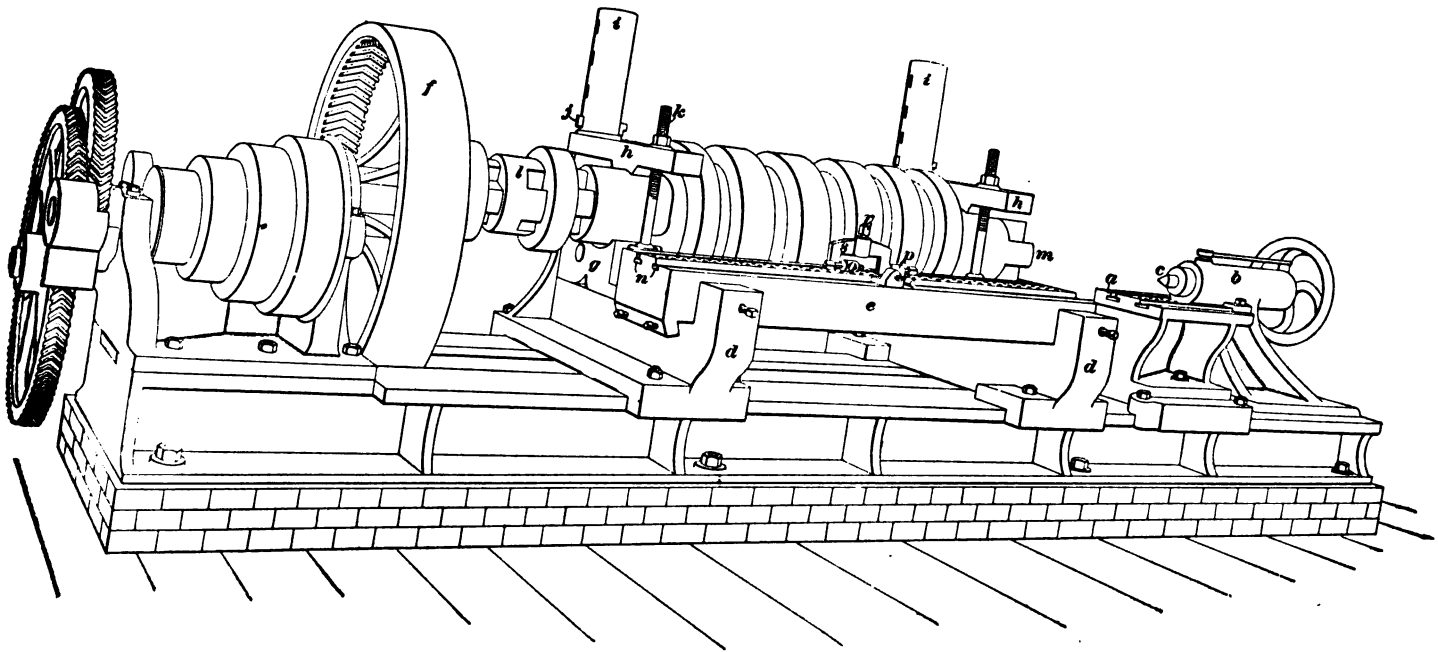


FIG. 6.

provided with a short carriage *a* for turning the bearings or for other similar work when it is necessary to traverse the carriage along the bed. The lathe is also provided with an ordinary tailstock *b* having a conical center *c*. This is employed when turning work between centers. The lathe is made very rigid and its bed is firmly bolted to the foundation. The supports *d* that carry the tool rest *e*, together with the tool rest, are made very rigid and massive, so that all vibration may be absorbed and there may be no lost motion whatever.

14. Holding the Work.—When the casting for a roll first comes from the foundry, it usually has a large riser head on one end that has to be cut off. This is ordinarily done in a regular engine lathe, and both ends of the roll shaft are trued up and centered in the lathe. Care must be taken to true the roll by the outside of the chill, so that during the subsequent turning of the chilled part there will be the least possible amount of stock to be removed. The surfaces for the bearings are then turned with the roll supported on ordinary conical centers in the ends of the roll shaft. The tailstock *b* and center *c*, Fig. 6, may be employed for this purpose, a regular center being introduced into the face plate *f* and the bearing turned by means of a tool or tools supported on a carriage *a*.

15. After the bearings have been turned either in the regular turning lathe or in an ordinary engine lathe, the roll is mounted in special housings, as shown at *g* and *h*. The lower half of the bearing *g* is supported largely on the bridge *d* that extends across the lathe and carries the tool rest *e*, and the upper half of the bearing *h* is made adjustable, one end of it being secured to the column *i* by means of suitable keys *j* and the other end held in place by the bolt *k*. This affords ample bearing surface for the support of the roll during turning and insures the turned portion being concentric with the bearings. The roll must not be rigidly attached to the face plate *f*, but is driven by means

of a universal coupling *l*. Sometimes, in order to take up any end motion of the roll, a piece is placed in the center in the end *m* of the roll and the other end of the piece placed against the center *c*, thus forcing the roll toward the bearing *g* and taking up all end motion.

16. Turning Tools.—The turning tools employed in turning rolling-mill rolls do not differ greatly in principle from those employed in turning parallel rolls; but in most cases the amount of parallel turning is considerably less, and cheaper tools can be used for the purpose. In turning rolling-mill rolls, higher and stiffer tools must be used for the grooving and similar work, and it would not be practicable, therefore, to use the thin tools ordinarily employed for turning the surfaces of parallel rolls, as the cutting edges would be so far below the center of the roll that they would have an excessive amount of clearance and hence become dull very quickly.

17. A good form of tool employed for surfacing rolling-mill rolls preparatory to grooving them is shown in Fig. 7. This consists of a bar of steel from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inches square with four grooves cut the entire length of the bar along the middle of each face, as shown. The tool is hardened as hard as fire and salt water will make it, and is then

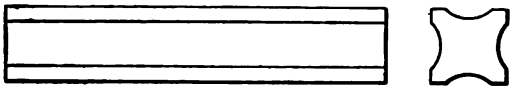


FIG. 7.

ground flat across each face, thus giving four cutting edges, one at each of the four corners. The grooves along the sides are made to reduce the amount of grinding necessary to sharpen the corners. Facing tools are also sometimes made by welding a piece of flat steel to the face of a piece of flat iron to bring the thickness up to an inch or more, then hardening and grinding as in the case of an ordinary tool; this method of facing cutters, however, is not as

advantageous as the one previously given, as it permits of only one edge, or, at the most, two edges, of the steel being employed as cutting edges.

18. Grooving Tools.—For all grooves having a circular cross-section, very efficient grooving tools may be made by turning up short cylinders of tool steel to the desired diameter, hardening them, and grinding the ends true. One of these tools is shown in Fig. 8. When it is desired to turn a groove to roll ovals, one of these circular tools is simply sunk into the face of the roll a short distance; when it is desired to turn grooves for rolling circular rods, a tool of the proper diameter is sunk into the roll to half of its depth. These tools are ground on both ends and can be used in at least four positions before they require regrinding; i. e., both the front and the back edges at the top and the bottom can be used.

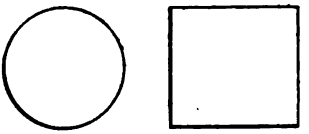


FIG. 8.

19. For turning rectangular grooves whose sides are either parallel or perpendicular to the length of the roll, a plain rectangular tool similar to a cutting-off tool is employed, as shown in Fig. 9. These tools, when narrow, are

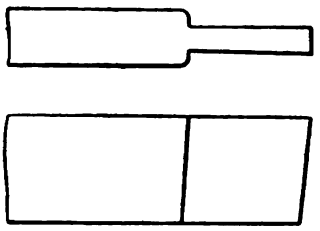


FIG. 9.

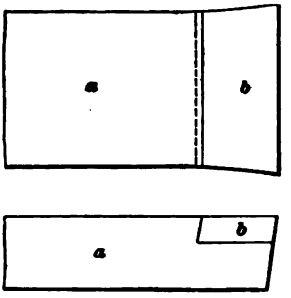


FIG. 10.

made wholly of steel; when wide, they may be made partially of steel and partially of iron, as shown in Fig. 10. A piece of wrought iron *a* is split open and worked out on the end to

receive the piece of steel *b*, which is welded into the wrought iron and hardened, after which the tool is ground and used as though it were a solid steel tool.

20. For turning rectangular or other polygonal grooves in which some of the faces of the grooves are neither parallel nor perpendicular to the axis of the roll, it becomes necessary to employ tools having special forms. For roughing out grooves for rolling squares, a tool similar to that shown in Fig. 11 may be employed, this tool being made of a wrought-iron body *a* with a steel cutting face *b*. It will also be noticed that the point *c* of the tool has been ground off to reduce the liability of its breaking. After this tool has been sunk into the groove to such a depth as to give the groove approximately its right width at the surface of the roll, another tool having a sharp point is introduced to remove the stock left by the point *c*.

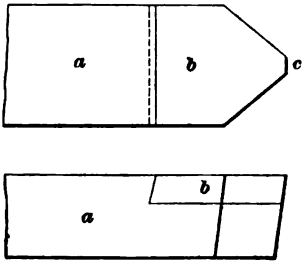


FIG. 11.

21. Sometimes it becomes necessary to face up the sides of grooves, in which case a tool of the style shown in Fig. 12 may be employed. This tool may be made of solid steel, as shown in the illustration, or may be made with a piece of steel welded to the top, as shown in Figs. 10 and 11. It will be noticed that the cutting edges *a*, *b*, and *c* are all given clearance, so that the tool can cut before itself, or to the right or the left.

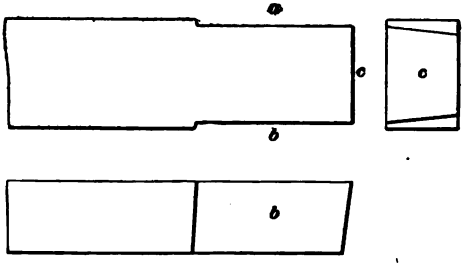


FIG. 12.

In turning irregular grooves, it is frequently necessary to make formed cutting tools. They may be made from solid

steel or by welding steel on iron, as shown in Figs. 10 and 11, and then grinding the cutting edge to the desired form. Sometimes the cutting edge is formed to approximately the desired form before hardening the tool. The tool is then hardened and the cutting edge ground to fit a templet of the desired form.

22. Clamping and Holding the Tools.—The tools employed in turning rolling-mill rolls are held in a manner very similar to those employed in turning parallel rolls, it always being necessary to clamp the tool as firmly as possible. The rest *e* of the lathe shown in Fig. 6 is provided with two T slots *n* and with rectangular holes in its upper surface, as shown. These rectangular holes are fitted with dogs *o* and *p*. The dogs *o* are similar to the ordinary planer plug, as shown in Fig. 13; the shank *a* is square or rectangular, depending on the form of the holes in the rest *e*, Fig. 6. In

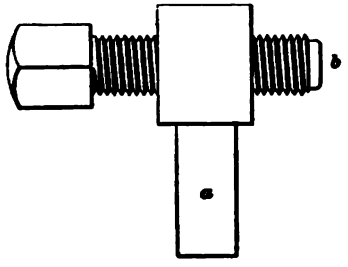


FIG. 13.

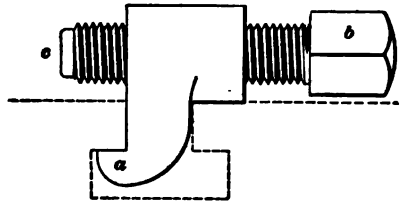


FIG. 14.

many cases these holes are rectangular, and, consequently, the point *a* is rectangular. The point *b* of the setscrew is brought into contact with the tool or the blocking. The dog *p*, Fig. 6, is of the general form shown in Fig. 14, and is arranged to fit into a T slot, as indicated by the dotted lines. The lug *a* is so formed that the dog can be easily removed from the T slot by simply lifting up on the head of the setscrew *b*, and when the point *c* of the setscrew is brought against the work, it will cause the lug *a* to take hold of the T slot and hold the work firmly in place. The tools are held

from behind and at the sides by means of the dogs shown in Figs. 13 and 14, and are held down by means of the clamps or setscrews *r* in the clamp *s* shown in Fig. 6.

23. When tools of the general form shown in Fig. 8, intended for turning circular grooves, are to be clamped, they are held against the work by means of special blocks provided for the purpose, as shown in Fig. 15, *a* being the block and *b* the cutting tool. A setscrew is brought to bear against the end *e* of the block *a* to crowd the edge *c* of the cutting tool against the work, as indicated by the dotted lines *f g*. The tool rest *d* is placed as far under the block *b* as possible, and in some cases no clamp is placed on top of the block *b*, the resistance along the edge *c* being depended on to hold it down against the rest *d* and in the slot in the end of the piece *a*. The piece *a* is held by means of the screw *r* in the clamp *s*, Fig. 6.

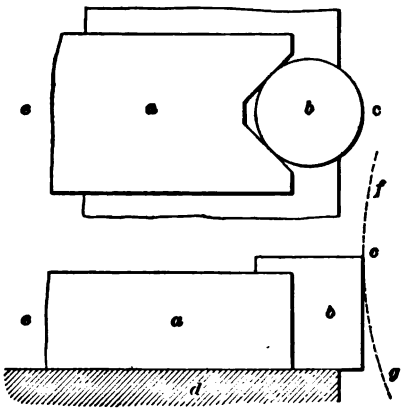


FIG. 15.

24. Allowance for Hot Iron. — In turning grooves for rolling-mill work, it is necessary to make the grooves somewhat larger than the standard bars they are intended to roll. To meet these requirements, an allowance of $\frac{1}{64}$ inch per inch is usually considered sufficient. For instance, a tool to cut a groove for rolling a 1-inch round bar would have to be $1\frac{1}{64}$ inches in diameter, and a groove for rolling a $3'' \times \frac{1}{2}''$ flat bar would have to be $3\frac{3}{64}$ inches wide, and similar allowances would be required for all shapes. All the tools employed in roll turning may be finished by grinding after tempering, if so desired.

GRINDING CHILLED ROLLS.

25. General Consideration.—Chilled rolls intended for use in flouring mills, calender rolls for paper-making machinery, and rolls for rolling some classes of sheet metal are finished by grinding. This is done to give a smooth surface and to insure the roll being parallel throughout its length.

26. Grinding Machine.—A machine for grinding flouring-mill rolls is illustrated in Fig. 16. The roll *a* is mounted in bearings *b* so that it is rigidly supported and revolved on the bearings on which it will ultimately work, thus insuring that the ground surface will be true with the bearings. The roll must be driven by some flexible coupling so as to allow it to run free in the bearings with no danger of cramping or displacement. This is accomplished by means of the universal coupling shown at *c* and the driving rod *d*. This driving rod *d* extends through the spindle *e* of the grinding machine and is secured by means of a universal joint at the driving-wheel end of the spindle.

The grinding is done by means of two emery wheels mounted on opposite sides of the roll, so that they act as a pair of calipers, the roll being ground between them. The emery wheels are driven by belts *f*, *f* and *g*, *g* and are adjusted by means of hand wheels, one of which is shown at *h*. The emery wheels are supported on a carriage *i*, which is traversed backward and forward on the bed *j* so that the wheels pass over the entire length of the roll. The roll is revolved by means of the belt *k* running upon a large band-wheel *l* shown at the end of the machine, and the machine is arranged with suitable mechanism for traversing the carriage automatically, the length of the traverse being adjusted by means of stops. The emery wheels are mounted as shown in detail in Fig. 17. The emery wheel *a* is supported on a spindle *b* provided with conical ends *c*, *c*. These conical ends are carried in Babbitt bearings *d*, *d*. Mounted on the spindle *b* are two pulleys *e*, *e* on which the driving belts run.

The emery wheel is surrounded by a suitable hood *f*. The Babbitt bearings *d* are turned on the outside to fit bearings in the frame, as shown at *g*, *g*, and the adjustment in the

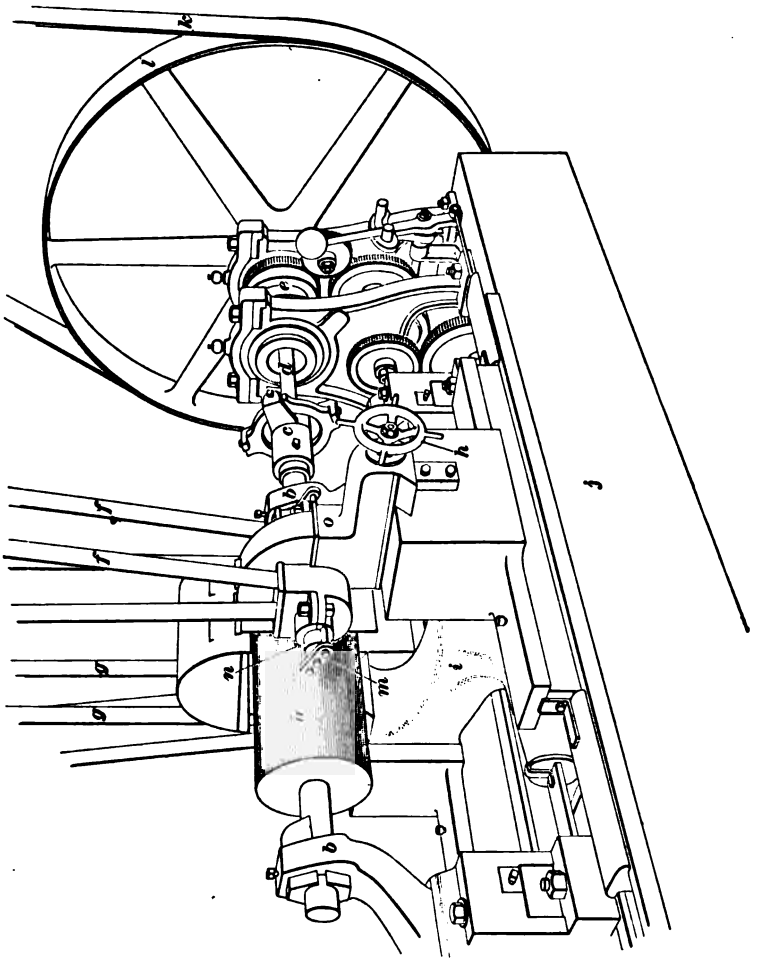


FIG. 16.

direction of the length of the spindle is controlled by means of the yokes *h*, *h* secured by studs as shown. By properly adjusting the bearings *d*, all end motion and play in the

emery-wheel spindle can easily be taken up. In grinding chilled rolls, it is necessary to be very careful about the adjustments of the emery wheel in order to be sure that there is no lost motion. The clamp yoke *h* in Fig. 17 is shown at *m*, Fig. 16, and the end of the Babbitt bearing is also shown at *n*, while the guard for the emery wheel

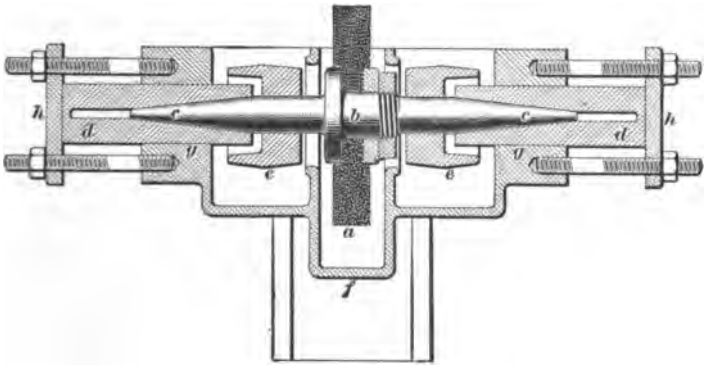


FIG. 17.

is shown at *o*. Rolls of larger diameter, such as large calender rolls, etc., are frequently ground on heavy machines especially manufactured for this purpose and so arranged that the emery wheels are placed in a swinging frame that constantly calipers the rolls. This is known as the J. Morton Poole grinding machine, which is described in *Grinding*.

27. Grinding Rolls. — For 12-inch rolls, the emery wheel should be 14 inches in diameter. One firm manufacturing a great many flouring-mill rolls employs a No. 2 grade, grain 80, carborundum wheel, though any wheel of corresponding grade and grain may be employed. If the 14-inch wheel is employed, it should be given about 1,600 revolutions per minute, and a 12-inch roll should be given about 30 revolutions per minute.

There must be plenty of soda water running on the wheels and the rolls during grinding, to keep the roll cool and to

carry off the dust. The operator adjusts the bearings *b*, Fig. 16, until the roll is in perfect alinement with the travel of the carriage *i*, and next adjusts the emery wheels to take equal cuts. The emery wheels are moved up by hand as the roll is gradually reduced until the desired size is obtained.

28. Testing Rolls.—If the rolls are properly ground they should fit perfectly, and in order to test them an arrangement similar to that shown in Fig. 18 is employed. A small carriage *a* is provided with carefully planed parallels *b* and *c*. Two rolls are laid on these parallels, as shown at *d* and *e*. The hose *f* is connected to a gas fixture and a series of gas burners are arranged on the pipe *g* so that they furnish a bright light back of the joint between the rolls. If the work has been properly done, no light whatever can be seen between the rolls, as they rest on each other and on the parallels. This gives an extremely delicate test of the accuracy of the workmanship on the rolls.

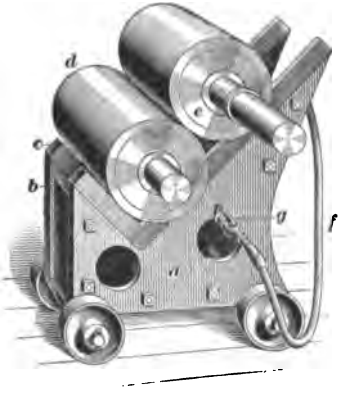


FIG. 18.

PLANING CHILLED IRON.

CORRUGATING ROLLS.

29. General Consideration.—Some of the rolls employed in flouring mills have to be corrugated after they are turned and ground. The corrugations are shallow grooves planed in the face of the rolls; they are not parallel to the

length of the roll, but have a slight spiral. These grooves are found necessary in certain classes of grinding rolls, not only to cause material to feed properly, but to produce the desired result upon the material being ground.

30. Corrugating Machine.—The machine employed for corrugating rolls is similar to a planing machine. One type of this class of machine is illustrated in Fig. 19, in which *a* is the roll being grooved. The weight of the roll is carried on suitable bearings *b*. The tailstock *c* is provided with a center that takes up any longitudinal movement of

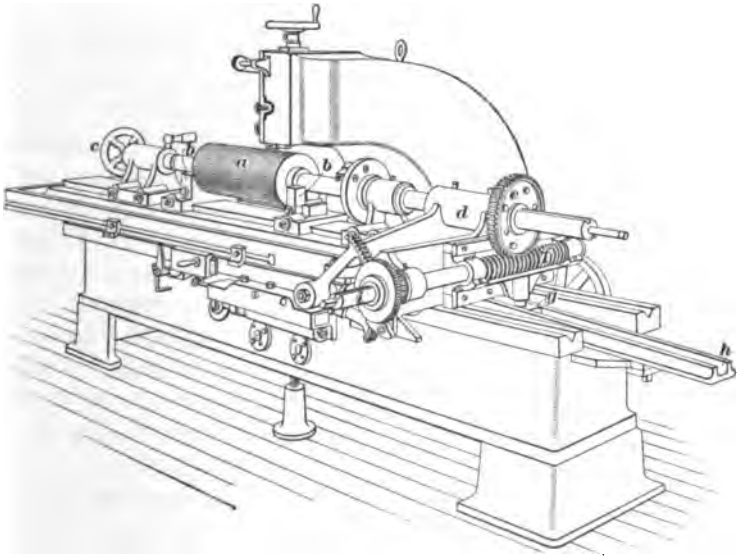


FIG. 19.

the roll, and the headstock *d* is provided with the necessary mechanism for rotating the roll through the proper angle to give the desired spiral. In the type of machine shown this is accomplished by means of a worm-wheel *e* and a worm *f*. The worm is made long so that it serves as a rack. It is controlled by the slide *g* traveling in the slot *h*. This slide carries the worm across the grooving machine as the roll

advances, and so rotates the worm-wheel *e* through a portion of a revolution during each stroke of the machine. The proper number of divisions or teeth are obtained by means of an automatic spacing device shown at the left-hand end of the worm-shaft *i*. This spacing device gives the shaft *i* a portion of a revolution after each stroke of the machine, thus advancing the cutting tool to the next groove.

31. Grooving the Rolls.—In grooving rolls, a wide tool similar to that shown in Fig. 20 is employed. This tool is made of $\frac{3}{4}'' \times 1\frac{1}{2}''$ steel. The tool is milled on the end with the kind of corrugation wanted, after which it is hardened. The tool is so set in the machine that it starts to cut on one side and each succeeding tooth takes a deeper cut, until the last one finishes the cut to the required depth. This rule holds good if the corrugations are not so large that considerable metal must be removed. In such cases it may be necessary to go around the roll twice to finish the grooves. In ordinary practice it is not possible to take a cut of over $\frac{15}{1000}$ inch in planing chilled iron, and, unless wide tools with a number of teeth are employed, it will take a very long time to do the grooving. In Fig. 20 the curved line *a b* represents the circumference of the roll, and it will be seen that each succeeding tooth takes a slightly deeper cut than the preceding, the tooth *c* finishing the groove. In grooving rolls, a speed of approximately 24 inches per minute is usually employed, and in some cases a speed slightly above this. One reason why a slightly higher speed can be employed in grooving than in turning rolls is to be found in the fact that the grooving tool is cutting during only a portion of the time, while the turning tool is under a constant strain.

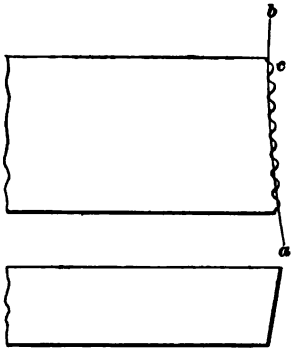


FIG. 20.

PLANING CHILLED-IRON DIES.

32. General Consideration.—It is frequently necessary to plane chilled-iron dies for pressed-brick machines, swage or anvil blocks, drop-hammer dies, and similar purposes. This work may be accomplished by making the speed of the planer sufficiently slow and the tools sufficiently rigid. In some cases, dies are planed by feeding a broad, square-nosed planing tool directly down on the face of the die, a slight amount of feed being given after each cut. When the width of the tool has been finished, it is moved along and a corresponding cut taken down to the proper depth. This method of procedure is exactly like that employed in turning chilled rolls. In other cases a fairly broad-nosed planing tool is adjusted so that it will act both as a roughing and a finishing tool and is given a slight feed across the planer after each cut, the cutting edge of the tool being of the general form shown somewhat exaggerated in Fig. 21; the portion *a b* is parallel to the surface of the work to be planed, and the portion *a c* is inclined so that it will act as a roughing tool to prepare the surface for the finishing cut. Such a tool as this is given a very slight clearance. It is possible to follow this practice of feeding sidewise in planing where it would not be possible to do so in lathe work, on account of the fact that all the feed occurs at the end of the stroke before the tool begins to cut, while in lathe work it is necessary to feed the tool sidewise during the cut.

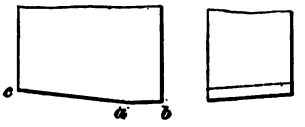


FIG. 21.

GEAR CALCULATIONS.

GEARING.

SPUR GEARS.

INTRODUCTION.

1. Object of Gearing.—Gearing is a term sometimes applied to any method of transmitting motion from one shaft to another, and includes all such combinations as pulleys and belts, rocker-arms and links, and toothed wheels. It is the object of gearing to transmit power or motion with as little loss as possible. Many of the problems relating to the different methods of transmission are similar, yet each method has its separate and distinct field of usefulness. When the rotating shafts are near each other and it is desired to transmit power without slipping or loss of motion, the gear has its greatest usefulness. The two shafts may run at the same or at different numbers of revolutions per minute. In this section only the class of gearing known as toothed gearing is dealt with.

2. Velocity Ratio.—The number of revolutions per minute of one shaft divided by the number of revolutions per minute of the other is called the **velocity ratio.** Let two wheels with parallel axes be held in firm rolling contact

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by pressure upon their axes, as in Fig. 1. If one wheel be turned in either direction, and there is no slipping, the other wheel will rotate in the opposite direction with a circumferential, or surface, velocity equal to that of the first; the relative motion will be the same as if the wheels were connected with a crossed belt, and the numbers of their

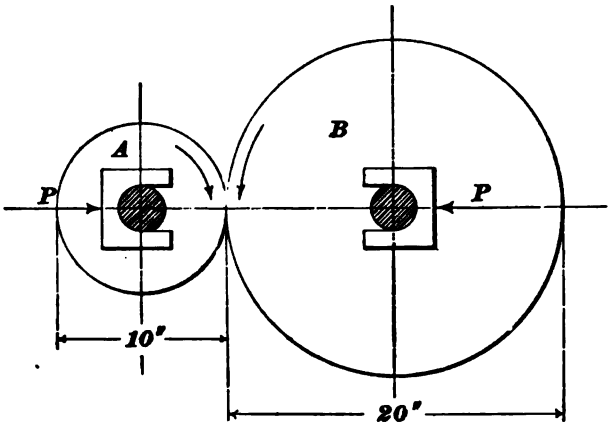


FIG. 1.

revolutions will be inversely proportional to their circumferences or to their diameters. The diameter of B being twice the diameter of A, the circumference of B is twice the circumference of A. Hence, when B makes 1 revolution A must make 2, or else there will be slipping between A and B.

3. Preventing Slipping.—Should slipping occur, B would make less than one-half as many revolutions as A, assuming A to be the driver. In order that this slipping may be prevented, suppose that pieces like a, a, Fig. 2, are fastened at equal distances on the peripheries of A and B, and that corresponding grooves like b, b are cut. Then, the projections, or teeth, on one wheel will run between the teeth on the other, and B will necessarily revolve with the

same circumferential velocity as A; that is, on each gear the same number of teeth will pass a given point in a

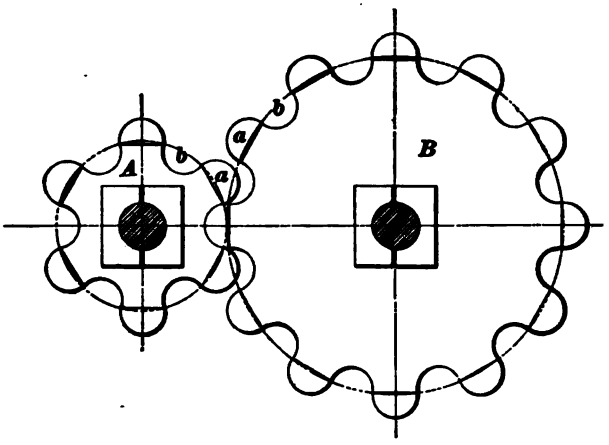


FIG. 2.

given time. When a wheel is supplied with teeth upon its surface it is called a *gear*.

DEFINITIONS.

4. The following definitions are important and apply to all the principal classes of gearing, as spur gearing, bevel gearing, and worm-gearing.

A **gear-wheel** or **gear** may be defined as a machine element provided with projections called *teeth*, these teeth being so formed that they will transmit a definite motion to another element of the machine by engaging with similar projections on it. When the projections on a pair of gears fit into one another, or engage one another, the gears, or their teeth, are said to be in **mesh.**

5. A **spur gear** is a gear with the teeth on its outer circumference and projecting radially, as shown in Fig. 3. The spur gear is the simplest and most familiar type of gear, and the principles involved in the formation of its teeth

apply, with certain minor modifications, to the formation of the teeth of nearly every type of gear in common use; therefore, a study of the subject of gear-teeth can best be begun by a study of the formation of the teeth of the spur gear.



FIG. 3.

6. The **pitch cylinders** of spur gears are the imaginary cylinders on which the teeth are constructed and that roll together with the same relative speed as the gears themselves.

7. The **pitch circle** of a spur gear is a circle that represents the pitch cylinder. The pitch circle is shown in Fig. 4 in its relation to the gear-teeth.

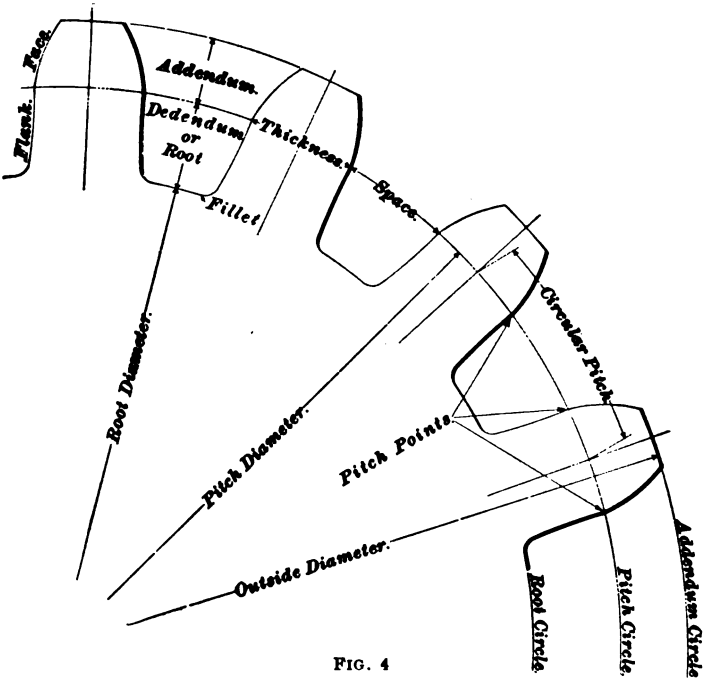


FIG. 4

8. The **pitch diameter** is the diameter of the pitch circle. When the word "diameter" is applied to gears, it is always understood to mean the pitch diameter, unless otherwise specially stated, as *outside diameter*, or *diameter at the root.*

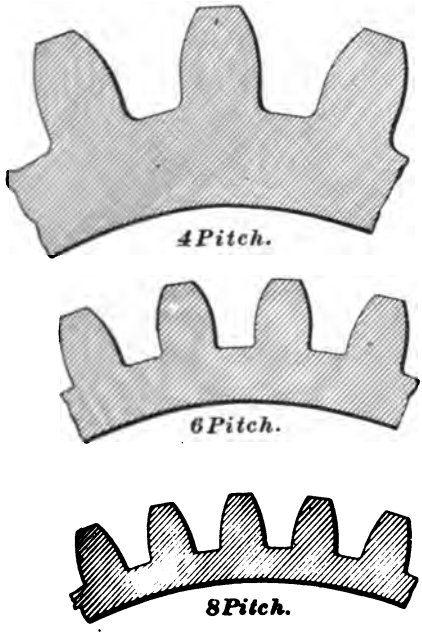


FIG. 5.

9. The distance from a point on one tooth to the corresponding point on the next tooth, measured along the pitch circle, is called the **circular pitch**; it is obtained by dividing the length of the circumference of the pitch circle by the number of teeth in the gear. The circular pitch is shown in Fig. 4.

10. Diametral pitch is the number of teeth in a gear divided by the number of inches in the diameter of the pitch circle. It has also been defined as the number of teeth in a gear 1 inch in diameter. It is obtained by dividing the number of teeth by the pitch diameter, and hence is equal to the number of teeth per inch of diameter. A gear, for example, has 60 teeth and is 10 inches in diameter; its diametral pitch is $\frac{60}{10} = 6$, and the

gear is therefore called a 6-pitch gear. It therefore follows that teeth of any particular diametral pitch are of the same size and have the same width on the pitch line, whatever may be the diameter of the gear. Thus, if a 12-inch gear has 48 teeth, it will be 4-pitch. A 24-inch gear having teeth of the same size will have twice 48, or 96, teeth—since its circumference is twice as long—and its diametral pitch is $96 \div 24 = 4$, the same as before. Fig. 5 shows the sizes of teeth of various diametral pitches.

The diametral pitch multiplied by the circular pitch of the same gear equals 3.1416. Using for illustration, a wheel 10 inches in diameter with 60 teeth, we have

$$\text{Circular pitch} = \frac{\text{circumference}}{\text{number of teeth}} = \frac{10 \times 3.1416}{60} = .5236 \text{ inch.}$$

$$\text{Diametral pitch} = \frac{\text{number of teeth}}{\text{diameter}} = \frac{60}{10} = 6.$$

The product of the two is $6 \times .5236 = 3.1416$.

11. The **thickness** of gear-teeth means the thickness measured on the pitch circle, as shown in Fig. 4.

12. The **space** in gear-teeth means the space between gear-teeth measured on the pitch circle. The thickness of a gear-tooth plus the space equals the circular pitch.

The **addendum** is the part of a gear-tooth outside the pitch circle, as shown in Fig. 4. The **addendum circle** is a circle through the extreme outside of the gear-teeth; its diameter is equal to twice the addendum plus the pitch diameter.

13. The **root,** or **dedendum,** is the part of the teeth inside the pitch circle, as shown in Fig. 4. The **root circle** is the circle that limits the bottom of the space between the teeth. The roots of the teeth are usually connected to the root circle by a short curve, so that there shall be no sharp corner. The curve that fills up the corner, as shown in Fig. 4, is called a **fillet.**

14. **Backlash** is the side clearance between two teeth in mesh; it is equal to the difference between the space and the thickness of a tooth, measured on the pitch circle.

15. The **clearance** is the space between the top of a tooth and the bottom of the space into which the tooth meshes when they are on the line connecting the centers of the gears. It is equal to the root minus the addendum.

16. The **line of centers** is the straight line drawn from the center of one gear to the center of another, with which it works when the pitch circles touch each other. The line of centers passes through the point of tangency of the two pitch circles.

17. The **pitch point** of a tooth curve is the point in which the outline of the tooth intersects the pitch circle. The term "pitch point" is defined in books on machine design as the point of tangency of the pitch circles of two gears working together. The first definition, however, is more in accordance with the use of the term in shops, and will be used here.

18. The **face** of a tooth is the working surface of the tooth from the pitch line to the top of the tooth; the **flank** is the surface from the pitch line to the bottom of the tooth.

19. The **length** of a tooth is the distance from root circle to the addendum circle; it is equal to one-half the difference between the root diameter and the outside diameter.

20. The **breadth,** or **width,** of a tooth is the distance from one flat surface or end to the other, or the distance from one top edge to the other top edge; it is measured at right angles to the length of the tooth.

21. A **gear blank** is the cylindrical piece of metal or other material in the outer circumference of which gear-teeth are to be cut. The blank is turned up equal to the outside diameter of the gear, and the teeth are then cut about its periphery.

22. When two gears are so located that their teeth run together, the gears are said to be in **mesh.**

23. A **rack** is a gear with a pitch circle having an infinite radius, that is, the pitch cylinder has become a plane, so that all the teeth are arranged in a straight line.

24. A **pinion** is a small spur gear. The term is used especially for small gears that mesh with racks.

PROPORTIONS FOR GEAR-TEETH.

25. Gear-Teeth Based on Circular Pitch.—The **relative proportions of gear-teeth** are usually based on the circular pitch. It is customary to have the addendum, the whole depth, and the thickness of the tooth conform to some arbitrary part of the circular pitch. There is no uniformly adopted standard, and gears made in different ways require different proportions. Cut gears require less backlash and clearance than cast gears. This is because the teeth of cut gears are more uniform in size, regular in outline, and truer in form than those of cast gears. Gears of large diameter require less backlash than those of small diameter. The proportions given in Table I are those in common use.

TABLE I.

GEAR-TOOTH PROPORTIONS.

	1	2	3	4
Addendum	.30 C	.30 C	.30 C	$1 \div P$.
Root	.40 C	.40 C	.35 C	$1.157 \div P$ to $1.125 \div P$
Working depth of tooth	.60 C	.60 C	.60 C	$2 \div P$
Total depth of tooth	.70 C	.70 C	.65 C	$2.157 \div P$
Clearance	.10 C	.10 C	.05 C	$.157 \div P$ to $.125 \div P$
Thickness of tooth	.45 C	.475 C	.485 C	$1.51 \div P$ to $1.57 \div P$
Width of space	.55 C	.525 C	.515 C	$1.63 \div P$ to $1.57 \div P$
Backlash	.10 C	.05 C	.03 C	$.12 \div P$ to 0

Recently some manufacturers have made gears with shorter teeth than those indicated in Table I. In some

cases the total depth of teeth was not more than five-tenths the circular, or $1\frac{1}{2}$ divided by the diametral, pitch. The width of tooth and space remained the same except that the backlash might be slightly reduced.

The Brown & Sharpe Company make the clearance one-tenth the thickness of the tooth on the pitch line, and The Pratt & Whitney Company make it one-eighth the addendum.

The proportions given in the foregoing table have been used successfully and will serve as an aid in deciding upon suitable dimensions. Column 1 is for rough cast gears where the teeth are very irregular, and consequently a large amount of backlash and clearance is required; column 2 is for the better class of cast gears; column 3 is for cut gears; and column 4 is for diametral pitch for cut gears. C stands for circular pitch, and P for diametral pitch.

26. Proportions of Gear-Teeth Based on Diametral Pitch.—As the gears most often met with are cut gears of diametral pitch, it would seem natural to proportion gear-teeth with the diametral pitch as a basis. It is much simpler to calculate gears using diametral pitch than when using circular pitch; hence, this system is coming into very general use for all classes of gearing.

Column 4 of Table I gives the proportions of gear-teeth based on this system as used by the leading manufacturers in this country.

RULES FOR SPUR-GEAR CALCULATIONS.

27. Relation Between Circular Pitch and Diametral Pitch.—The product of the circular pitch of a gear and the diametral pitch is always the constant number 3.1416. Hence the following rules:

Rule.—*To change circular pitch to diametral pitch divide 3.1416 by the circular pitch.*

EXAMPLE.—If the circular pitch is .3927 inch, what is the diametral pitch?

SOLUTION.—Applying the rule just given, the diametral pitch is

$$\frac{3.1416}{.3927} = 8. \quad \text{Ans.}$$

28. Rule.—*To change diametral pitch to circular pitch, divide 3.1416 by the diametral pitch.*

EXAMPLE.—If the diametral pitch is 4, what is the circular pitch?

SOLUTION.—Applying the above rule, the circular pitch is

$$\frac{3.1416}{4} = .7854 \text{ in.} \quad \text{Ans.}$$

29. Relation Between Pitch Diameter, Number of Teeth, and Diametral Pitch. — The relation between the pitch diameter, number of teeth, and diametral pitch is expressed in the following rules:

Rule.—*To find the number of teeth when the pitch diameter and the diametral pitch are known, multiply the pitch diameter by the diametral pitch.*

EXAMPLE.—If a wheel is 30 inches in diameter and 3 pitch, how many teeth has it?

SOLUTION.—Applying the rule just given, the number of teeth is

$$30 \times 3 = 90. \quad \text{Ans.}$$

30. Rule.—*To find the pitch diameter when the number of teeth and the diametral pitch are known, divide the number of teeth by the diametral pitch.*

EXAMPLE.—What is the pitch diameter of a 2½-pitch gear having 20 teeth?

SOLUTION.—By applying the rule just given, we find the diameter to be

$$\frac{20}{2\frac{1}{2}} = 8 \text{ in.} \quad \text{Ans.}$$

31. Rule.—*To find the diametral pitch when the number of teeth and the pitch diameter are given, divide the number of teeth by the pitch diameter.*

EXAMPLE.—If a gear contains 50 teeth and has a pitch diameter of 10 inches, what is its diametral pitch?

SOLUTION.—Applying the rule,

$$\frac{50}{10} = 5 \text{ diametral pitch.} \quad \text{Ans.}$$

32. Finding the Outside Diameter of a Gear-Blank.—The diameter to which the blank for a spur gear should be turned is equal to the outside diameter of the gear. By reference to Fig. 4 it is seen that the outside diameter, and, hence, the diameter of the blank, is equal to the pitch diameter plus twice the addendum.

With the diametral-pitch system, in which the addendum is equal to 1 divided by the pitch, the outside diameter may be calculated from the pitch diameter and the pitch by an application of the following rule:

Rule.—*To find the outside diameter, or the diameter of the blank, when the pitch diameter and the diametral pitch are known, divide 1 by the pitch, multiply the quotient by 2, and add the product to the pitch diameter.*

EXAMPLE.—What should be the diameter of a gear-blank for a 6-pitch gear, when the pitch diameter is 14 inches?

SOLUTION.—Applying the rule just given, 1 divided by the pitch equals $1 \div 6 = \frac{1}{6}$; hence, the diameter of the blank is found to be

$$\frac{1}{6} \times 2 + 14 = 14.33 \text{ in.} \quad \text{Ans.}$$

33. Since the pitch diameter is equal to the number of teeth divided by the diametral pitch, and the addendum is equal to 1 divided by the diametral pitch, the sum of the pitch diameter plus twice the addendum, or the outside diameter of the gear, may be calculated by an application of the following rule:

Rule.—*To find the outside diameter, or the diameter of the blank, when the diametral pitch and the number of teeth are known, add 2 to the number of teeth and divide the sum by the pitch.*

EXAMPLE.—A wheel is to have 48 teeth, 6 pitch; to what diameter must the blank be turned?

SOLUTION.—By the rule just given, the outside diameter is

$$\frac{48 + 2}{6} = 8.333 \text{ in.} \quad \text{Ans.}$$

34. Calculations Based on the Outside Diameter.—The diameter of the blank and the pitch being

given, the number of teeth may be calculated from the following rule:

Rule.—*To find the number of teeth when the outside diameter of the blank and the diametral pitch are known, multiply the outside diameter by the pitch and subtract 2 from the product.*

EXAMPLE.—A gear-blank measures $10\frac{1}{2}$ inches in diameter and is to be cut 4 pitch. How many teeth should the gear-cutter be set to space?

SOLUTION.—By applying the rule just given, we find the number of teeth to be

$$10\frac{1}{2} \times 4 - 2 = 42 - 2 = 40 \text{ teeth.} \quad \text{Ans.}$$

35. Rule.—*To find the diametral pitch when the outside diameter and the number of teeth are known, add 2 to the number of teeth and divide the sum by the outside diameter.*

EXAMPLE.—It is required to select a cutter for a gear having 54 teeth that is to mesh with the change gears of a lathe. One of the change gears, which has 64 teeth, measures 6.6 inches, outside diameter; for what pitch should the cutter be selected?

SOLUTION.—Applying the rule given, the pitch of the change gear is found to be $\frac{64 + 2}{6.6} = 10$; hence, this is the pitch of the cutter required. Ans.

36. In applying the rule given in Art. **35,** it will sometimes be found that the result obtained does not correspond with any standard pitch number; for example, a gear with 68 teeth measures $15\frac{9}{16}$ inches in outside diameter. Applying the rule to these values, the pitch would be $\frac{68 + 2}{15.5625}$ $= 4.4979+$; this number is so near to $4\frac{1}{2}$, which is a standard pitch, that it is evident that $4\frac{1}{2}$ is the pitch of the gear and that either the blank was not turned to the exact diameter called for by the pitch and number of teeth or that the exact diameter was not determined by the measurement. When a set of standard gear-cutters is available, the pitch of the gear can also be determined by trying different cutters until one is found that fits.

A considerable difference between the value obtained by applying the rule and the nearest standard pitch will indicate that an uncommon pitch has been used. In general, however, it may be assumed that the pitch is the standard whose number agrees most nearly with the value obtained from an application of the rule.

As far as practicable, the pitch and diameter should be so chosen that the number of teeth will correspond to a number of divisions that can be readily obtained with the aid of the indexing mechanism of the machine in which the gear is to be cut.

37. Relation Between Pitch Diameter, Number of Teeth, and Circular Pitch.—If any two of the factors named are given, the other can be found by applying one of the following rules:

Rule.—*To find the diameter of the pitch circle when the number of teeth and the circular pitch are known, take the continued product of the number of teeth, the circular pitch, and .3183.*

EXAMPLE.—What is the pitch diameter of a gear-wheel that has 75 teeth and whose circular pitch is 1.625 inches?

SOLUTION.—Applying the rule, the diameter is found to be

$$1.625 \times 75 \times .3183 = 38.79 \text{ in.} \quad \text{Ans.}$$

38. Rule.—*To find the circular pitch when the pitch diameter and the number of teeth are known, multiply the pitch diameter by 3.1416 and divide the product by the number of teeth.*

EXAMPLE.—What is the circular pitch of a gear 32 inches in diameter and having 84 teeth?

SOLUTION.—Applying the rule just given, the circular pitch is found to be

$$\frac{32 \times 3.1416}{84} = 1.1968 \text{ in.} \quad \text{Ans.}$$

39. Rule.—*To find the number of teeth when the pitch diameter and the circular pitch are known, multiply the pitch*

diameter by 3.1416 and divide the product by the circular pitch.

EXAMPLE.—How many teeth will there be in a gear-wheel 25 inches in diameter if the circular pitch is 1.309 inches?

SOLUTION.—By the rule just given, the number of teeth is

$$\frac{25 \times 3.1416}{1.309} = 60. \quad \text{Ans.}$$

40. Number of Teeth and Relative Velocities. If the number of teeth in one gear and the number of teeth and velocity of the other gear of a pair of gears are known, the velocity of the first gear may be found by applying the following rule:

Rule.—*To find the velocity of either gear in a pair of gears, when its number of teeth, the velocity, and the number of teeth of the other gear are known, multiply the known velocity by the number of teeth in that gear and divide the product by the number of teeth in the gear whose velocity is required.*

EXAMPLE.—At how many revolutions per minute will a gear with 16 teeth run when it is driven by a gear having 72 teeth and running at a velocity of 30 revolutions per minute?

SOLUTION.—Applying the above rule, the required velocity is found to be

$$\frac{72 \times 30}{16} = 135 \text{ rev. per min.} \quad \text{Ans.}$$

41. Velocity Ratio.—When comparing the velocities of two gears, instead of considering the number of revolutions made by each gear in a given unit of time as 1 minute or 1 second, it is often more convenient to use the ratio* between their respective velocities. This ratio is called the velocity ratio, and is the number of revolutions or parts of a revolution made by one of the gears for 1 revolution of the other. Its numerical value is obtained by dividing the number of revolutions of one gear in a

* By **ratio** of two numbers is meant the quotient obtained by dividing one number by the other; thus, the ratio of 20 to 4 is $20 \div 4 = 5$, and the ratio of 4 to 20 is $4 \div 20 = \frac{4}{20} = \frac{1}{5}$.

given time by the number of revolutions of the other gear in the same time, the number of revolutions of that gear whose velocity ratio is sought being used as the *dividend.* Instead of the numbers of revolutions in a given time, the numbers representing the diameters or number of teeth may be used to find the numerical value of the velocity ratio, in which case, however, the number of teeth of the gear whose velocity ratio is sought is used as the *divisor.*

The circumferences, diameters, and numbers of teeth are in the same ratio, but they are inversely as the velocity ratio.

EXAMPLE 1.—A pinion makes 150 revolutions per minute and drives a gear making 25 revolutions per minute. What is (*a*) the velocity ratio of the pinion with respect to the gear? (*b*) the velocity ratio of the gear with respect to the pinion?

SOLUTION.—(*a*) The velocity ratio of the pinion, that is, the number of revolutions it makes while the gear is making one, is, according to the foregoing rule, $\frac{150}{25} = 6$. Ans.

(*b*) The velocity ratio of the gear, that is, the number of revolutions it makes while the pinion makes one, is $\frac{25}{150} = \frac{1}{6}$. Ans.

EXAMPLE 2.—A gear has 96 teeth, while the pinion meshing with it has 16 teeth. What is (*a*) the velocity ratio of the pinion? (*b*) the velocity ratio of the gear?

SOLUTION.—(*a*) Dividing the number of teeth of the gear by the number of teeth of the pinion, we get $\frac{96}{16} = 6$ as the velocity ratio of the pinion. Ans.

(*b*) In this case, we have $\frac{16}{96} = \frac{1}{6}$ as the velocity ratio of the gear. Ans.

EXAMPLE 3.—Two gears having diameters of 24 and 36 inches, respectively, mesh together; what are their velocity ratios?

SOLUTION.—The velocity ratio of the 24-inch gear is $\frac{36}{24} = 1\frac{1}{2}$; that is, it makes $1\frac{1}{2}$ revolutions while the 36-inch gear makes 1. The velocity ratio of the 36-inch gear is $\frac{24}{36} = \frac{2}{3}$; that is, it makes $\frac{2}{3}$ revolution while the 24-inch gear makes 1. Ans.

42. Diameters for Fixed Center Distances.—The relations between the diameters of gears and their center distances are expressed in the following rules:

Rule.—*To find the pitch diameter of the larger gear in a pair when the distance between centers of the two gears and*

their respective velocity ratios are fixed, multiply twice the distance between centers by the velocity ratio of the smaller gear and divide the product by the sum of the velocity ratios of the two gears.

EXAMPLE.—The smaller of two gears is to run five times as fast as the larger. The distance between centers being 12 inches, what must be the pitch diameter of the larger gear?

SOLUTION.—By an application of the rule just given, the pitch diameter of the larger gear is found to be

$$\frac{2 \times 12 \times 5}{5 + 1} = 20 \text{ in.} \quad \text{Ans.}$$

43. Rule.—*To find the diameter of the smaller gear in a pair when the distance between centers of the two gears and their respective velocities are fixed, multiply twice the distance between centers by the velocity of the larger gear and divide the product by the sum of the velocities of the two gears.*

EXAMPLE.—Taking the last example again, what should be the diameter of the smaller gear?

SOLUTION.—Applying the rule just given, we have, as the diameter of the smaller gear,

$$\frac{2 \times 12 \times 1}{5 + 1} = 4 \text{ in.} \quad \text{Ans.}$$

44. Since the distance between centers is equal to the sum of the radii of the two gears, it follows that when the diameter of either gear has been calculated, the diameter of the other may be found as follows:

Rule.—*To find the diameter of one gear of a pair of gears, when the distance between centers is fixed and the diameter of the other gear is known, subtract the known diameter from twice the distance between centers.*

EXAMPLE.—The distance between centers being 8 inches, and the diameter of one gear being 4 inches, what is the diameter of the other gear?

SOLUTION.—Applying the rule just given, we obtain

$$2 \times 8 - 4 = 12 \text{ in.} \quad \text{Ans.}$$

LAYING OUT GEAR-TEETH.

FORMS OF GEAR-TOOTH OUTLINES.

45. Constant Velocity Ratio.—In order that a tooth of the driving gear shall press on a tooth of the driven gear in such a manner as to produce a constant speed of turning while they are in contact, it is necessary that the curved outline of the teeth shall be constructed according to a certain law. The principle involved is that the line *i k*, Fig. 6,

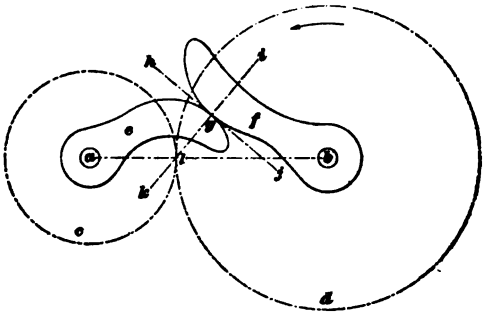


FIG. 6.

called the normal to the tooth curves at their point of tangency, that is, the point where they touch, must pass through the point of tangency of the pitch circles for every position in which the two teeth are in contact. When this condition is satisfied there will be a **constant velocity ratio** for the gears.

In Fig. 6, *c* and *d* are two pitch circles with their respective centers at *a* and *b*. The curve outlines *e* and *f* represent the teeth of two gears with these pitch circles. These curves are tangent to each other at *g*, and *k j* is a straight line tangent to both curves at the point *g*. A line perpendicular to this tangent line at *g* is the *normal* to both curves. Such a normal *k i* passes through the point of tangency *g* of the tooth curves and the point of tangency *l* of the pitch circles. The curves *e* and *f* are so designed that for every position in which they can be in contact their common normal passes

through the point of tangency of the pitch circles. These curves therefore satisfy the condition for constant velocity ratio.

46. Devices for Drawing Gear-Teeth.—An **odontograph** is an arrangement to facilitate the laying out of the curved outlines of gear-teeth. The term has been applied in a number of different forms, but its application to the templets for laying out the tooth curves seems to be the best, hence many persons define an odontograph as a templet for laying out gear-teeth. The term, however, has also been applied to tables that give the radii for the tooth-curve outlines of gears, though it would seem better practice to call these **odontograph tables.** In some cases the templet has to be used in connection with a table, the templet being simply a means for finding the centers from which to draw the tooth curves.

47. Tooth Curves in General Use.—As stated in Art. **45,** the motion transmitted by one gear to another will be smooth and uniform only when the teeth of the gears are given definite forms. Theoretically, the number of forms that meet these conditions is large; practically, however, owing to the necessity of simplicity and ease of construction, this number is restricted to a few simple types, while the importance of uniformity has still further restricted the types in common use to two general systems, known as the **involute,** or **single-curve,** system and the **cycloidal,** or **double-curve,** system. Of these two systems, the involute has a number of important advantages, especially when used for cut gears, that are constantly bringing it into more extensive use, and many of the best authorities on gearing urge its universal adoption to the exclusion of the cycloidal system.

INVOLUTE SYSTEM.

48. Definition of an Involute.—Mathematically, an **involute** is the curve that would be drawn by a pencil point at the end of a thin band, that will not stretch, and

that is drawn tight while being unwound from a cylinder. For example, suppose such a band to be unwound from the cylinder in Fig. 7, beginning with the pencil point at *a* on the circumference. As the band is unwound, the pencil point traces the curved line *a–1–2–3–4*, etc., which line is a part of the involute of the circle that represents the circumference of the cylinder. With true involute teeth, the path followed by the point of contact of the tooth curves of the teeth on the two gears is a straight line, called the **line of action,** that is tangent to the base circles of both gears. The faces of involute rack teeth are straight lines perpendicular to this line of action. In practice, the base circles are usually so chosen that the line of action makes an angle of 15° with a line that is tangent to both pitch circles at their point of tangency. As the faces of the rack teeth are perpendicular to the line of action, they make an angle of 75° with their pitch plane. In the approximate tooth curves frequently used in practice, the faces of the rack teeth are composed wholly or partially of curves.

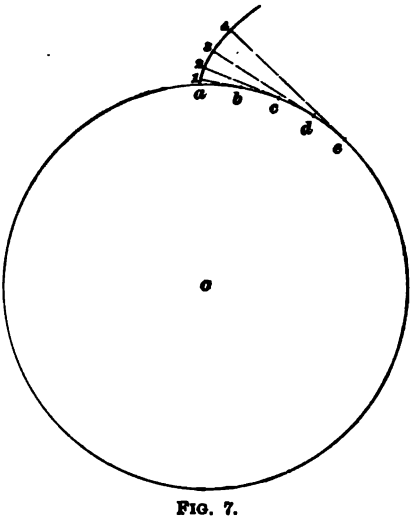


FIG. 7.

49. Base Circle for Involute Teeth.—The **base circle** in the involute system of gearing is the circle to which the involute that forms the outline of the tooth is drawn. The radius of the base circle is smaller than that of the pitch circle, the difference between the two being generally found by multiplying the pitch diameter by a number that is constant in any given system, but varies somewhat with different systems. For most purposes, a difference

between the radii of the two circles, or a distance between their circumferences D, Fig. 8, equal to $\frac{1}{60}$ of the diameter of the pitch circle, will give satisfactory results. Brown & Sharpe use a value of D slightly smaller than this, their rule being to make the *diameter* of the base circle equal to

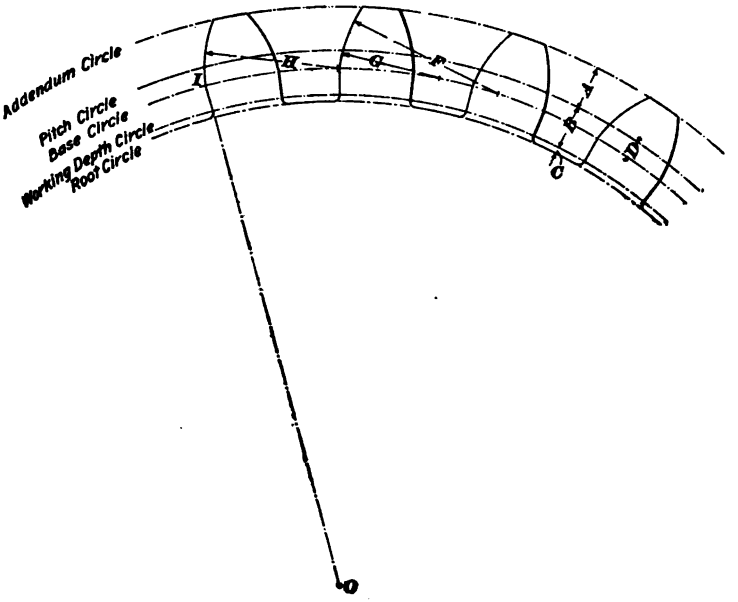


FIG. 8.

the product obtained by multiplying the diameter of the pitch circle by .968. In accordance with this rule, the distance D is equal to the diameter of the pitch circle multiplied by .016. This system is used more extensively than any other.

50. Example in Laying Out Teeth.—The general method of laying out the teeth is here described by means of an illustrative example: Let it be required to lay out the teeth for a gear 8 inches in diameter, 3 pitch. By the proportions stated in column 4, Table I, the addendum is $1 \div 3 = \frac{1}{3}$ inch, the working depth is $2 \times \frac{1}{3} = \frac{2}{3}$ inch, and the

clearance, using The Pratt & Whitney Company's proportions, is $\frac{1}{8} \times \frac{1}{3} = \frac{1}{24}$ inch. By Art. **49**, the distance from the pitch circle to the base circle is $\frac{1}{16} \times 8 = \frac{8}{16}$ inch. First draw the pitch circle, see Fig. 8, with a diameter of 8 inches, then draw the addendum circle, the base circle, the working-depth circle, and the root circle, making the distances A, B, C, and D, respectively, $\frac{1}{3}$, $\frac{1}{3}$, $\frac{1}{24}$, and $\frac{8}{16}$ inch, in accordance with the calculated values. If no scale by means of which these fractions can be laid off directly is available, they may be reduced to decimals and laid off with a decimal scale.

The pitch being 3, the number of teeth is $3 \times 8 = 24$. The circumference of the pitch circle must therefore be divided into 24 equal parts, each of which is to be subdivided into 2 parts, which represent, respectively, the thickness of the tooth and the width of the space on the pitch line. The points of division between these subdivisions of the pitch circle are the pitch points of the teeth; the outlines of the teeth must pass through these points.

The work is now ready for the construction of the tooth curves between the base circle and the addendum circle. These curves are generally circular arcs drawn with centers on the base circle, so as to agree as closely as is practicable with the theoretical curves for the tooth. Two methods of drawing them are described in the following articles.

51. Single-Arc Approximation.—By the following method, known as the **single-arc approximation,** the outline of the tooth between the base circle and the addendum circle is the arc of a circle drawn through the pitch point with a center on the base line and a radius H, Fig. 8, equal to one-fourth the radius of the pitch circle. In the example under consideration, see Art. **50**, the radius of the pitch circle is $8 \div 2 = 4$ inches, and the radius H with which to draw the tooth outline is $4 \times \frac{1}{4} = 1$ inch. When the number of teeth is greater than 30 and the diametral pitch is not less than 10, this method will give a curve that will be satisfactory for most ordinary work. With larger teeth,

TABLE II.

GRANT'S INVOLUTE ODONTOGRAPH TABLE.

No. of Teeth.	Divide by the Diametral Pitch.		Multiply by the Circular Pitch.	
	Face Radius.	Flank Radius.	Face Radius.	Flank Radius.
10	2.28	.69	.73	.22
11	2.40	.83	.76	.27
12	2.51	.96	.80	.31
13	2.62	1.09	.83	.34
14	2.72	1.22	.87	.39
15	2.82	1.34	.90	.43
16	2.92	1.46	.93	.47
17	3.02	1.58	.96	.50
18	3.12	1.69	.99	.54
19	3.22	1.79	1.03	.57
20	3.32	1.89	1.06	.60
21	3.41	1.98	1.09	.63
22	3.49	2.06	1.11	.66
23	3.57	2.15	1.13	.69
24	3.64	2.24	1.16	.71
25	3.71	2.33	1.18	.74
26	3.78	2.42	1.20	.77
27	3.85	2.50	1.23	.80
28	3.92	2.59	1.25	.82
29	3.99	2.67	1.27	.85
30	4.06	2.76	1.29	.88
31	4.13	2.85	1.31	.91
32	4.20	2.93	1.34	.93
33	4.27	3.01	1.36	.96
34	4.33	3.09	1.38	.99
35	4.39	3.16	1.39	1.01
36	4.45	3.23	1.41	1.03
37–40	4.20		1.34	
41–45	4.63		1.48	
46–51	5.06		1.61	
52–60	5.74		1.83	
61–70	6.52		2.07	
71–90	7.72		2.46	
91–120	9.78		3.11	
121–180	13.38		4.26	
181–360	21.62		6.88	

however, and especially with wheels having a small number of teeth, the curve so obtained differs considerably from the correct curve and, in these cases, more satisfactory results are obtained by the method explained in the following articles.

52. Grant's Involute Odontograph Table.— By this method, for all gears having fewer than 37 teeth, the curve is approximated by two circular arcs—one extending from the pitch circle to the addendum circle and the other from the pitch circle to the base circle—having different radii, the center of the arc for each being on the base circle.

The lengths of the radii with which the two arcs are drawn are obtained by the following method: In Table II, which is taken from Grant's "Treatise on Gear-Wheels," are two sets of numbers, a part of each set being in two columns. The first set has the general heading Divide by the Diametral Pitch and the two columns in this set have the respective headings Face Radius and Flank Radius. This set is to be used with the diametral-pitch system. To find the radius F, Fig. 8, for the face of a tooth for a gear having less than 37 teeth, divide the number in the column headed Face Radius, opposite the number that corresponds with the number of teeth in the gear, by the diametral pitch. To find the radius G of curved part of the flank, divide the corresponding number in the column headed Flank Radius by the diametral pitch.

The second set of two columns of numbers is headed Multiply by the Circular Pitch and is to be used with the circular-pitch system. It is used in the same manner as the first set, except that the numbers taken from the table are to be *multiplied* by the circular pitch.

Applying this method to the diametral-pitch gear of Art. **50**, in which the number of teeth is 24 and the pitch 3, we proceed as follows: To find the radius of the face, we look in the first column for the number 24 and in the same horizontal line in the column headed Face Radius, we find the number 3.64, which, divided by the pitch, gives us

$3.64 \div 3 = 1.21$ inches as the radius F of the face. In the same horizontal line and in the column headed Flank Radius, we find the number 2.24; this number divided by 3 gives us $2.24 \div 3 = .75$ inch, nearly, as the radius G of the flank.

53. Odontograph Table for Gears Having More Than 36 Teeth.—An inspection of Table II shows that for gears having more than 36 teeth there is but one column of figures under each of the respective headings of diametral pitch and circular pitch. The reason is that the whole curve is drawn with a single radius, whose length is determined by the general method already explained. It is constant for all gears the numbers of whose teeth are included in the several pairs of numbers given in the column headed No. of Teeth; for instance, the length of the radius for all numbers of teeth from 37 to 40 is determined by the use of the numbers in the horizontal line in which these numbers occur.

EXAMPLE.—What is the length of the radius for the curves of the teeth of a gear having 64 teeth, 1.473 circular pitch ?

SOLUTION.—Since the number of teeth lies between the numbers 61–70 in the first column of the table, and the pitch is in the circular-pitch system, we multiply the pitch by the number 2.07, which is found in the second set of figures at the right of the numbers 61–70 and in the same horizontal row. Performing the multiplication, we get $1.473 \times 2.07 = 3.05$, say 3 in., as the length of the radius. Ans.

54. Completing the Tooth Outline.—With any of the foregoing methods of constructing the tooth outline, the flanks of the teeth are radial between the base circle and the working-depth circle; this part of the outline is therefore made to coincide with the straight line from the center O of the pitch circle to the point where the curved portion of the outline intersects the base circle, as is shown by the line OI in Fig. 8. A fillet from the working-depth circle connects the radial portion of the outline with the root circle and completes the outline of the tooth. Brown & Sharpe make the radius of this fillet equal to one-seventh the width of a space at the addendum circle.

55. Minimum Number of Teeth.— The smallest number of teeth that should be used in a cut gear whose teeth are laid out by the method of single-arc approximation is 30; with a smaller number, the difference between the curve obtained by this method and the correct curve is so great as to cause the teeth to work unsatisfactorily. By using Grant's odontograph table in the manner explained, it is possible to make satisfactory gears that have as few as 10 teeth.

56. Grant's Rule for Rack Teeth.—The teeth of a rack that is to mesh with an involute gear of a given pitch may be laid out by the following method, which is known as "Grant's rule for rack teeth." First draw the addendum, pitch, and root lines, Fig. 9, making the distances A and B each equal to 1 divided by the diametral

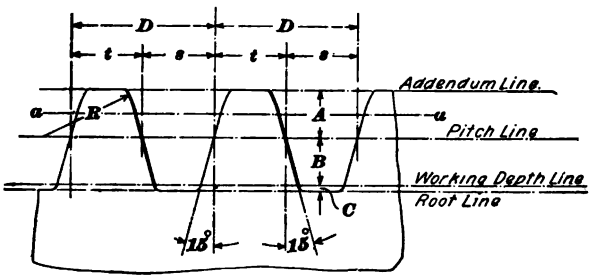


FIG. 9.

pitch, and the distance C equal to one-eighth of A. On the pitch line lay off the pitch distances D, D, and divide them into the two parts t and s, corresponding, respectively, to the thickness of the teeth and the width of the spaces on the pitch line. Draw the sides of the teeth from the working-depth line to the line $a\,a$, which is drawn half-way between the pitch line and the addendum line, as straight lines making angles of 15° with lines that pass through the pitch points perpendicular to the pitch line. Draw the outer half of the addendum as a circular arc having a

radius R whose length is 2.1 divided by the diametral pitch, or .67 multiplied by the circular pitch. A fillet from the working-depth line to the root line completes the outline of each side of the tooth.

CYCLOIDAL SYSTEM.

57. Definition of a Cycloid. — In mathematics, a **cycloid** is a path described by a point on the circumference of a circle as the circle rolls upon a straight line; thus, the curve $a\,b\,c$, Fig. 10 (a), described by the point b as the circle j rolls along the line $a\,c$ is called a cycloid. The circle j is called a **describing, or rolling, circle.** When the describing circle, as h, Fig. 10 (b), rolls upon the outside of another circle, as g, the curve $e\,d$ described by any point on the describing circle, as e, is called an **epicycloid.** If the describing circle, as i, rolls on the inside of another circle, as g, the curve $e\,f$ generated by any point of the describing circle, as e, forms what is called a **hypocycloid.** If the circle i has a diameter just one-half the diameter of the circle g, the hypocycloid will be a straight line, or a diameter of the circle g. If the diameter of the circle i is less than half that of the circle g, the hypocycloid will have a curve as shown at $e\,f$, while if the diameter of i is more than half the diameter of g, the curve will extend to the left from the point e instead of to the right of e.

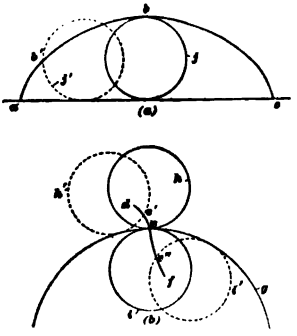


FIG. 10.

58. Laying Out Cycloidal Teeth. — The pitch, addendum, working depth, and root circles are drawn, and the pitch, thickness of teeth, and width of spaces on the pitch circle are laid off as described for the involute system.

After this the outlines of the teeth may be drawn as theoretical curves, but the more common method is to draw the curves for the faces and flanks as circular arcs that agree very closely with the theoretical curves.

59. Grant's Cycloidal Odontograph Table.—One of the most accurate practical methods of laying out the approximate curves of cycloidal teeth by means of circular arcs has been devised by Mr. George B. Grant. The lengths of the radii of the arcs and the location of their centers are determined by the pitch and number of teeth of the gear, in conjunction with a table of factors that apply to gears of all sizes from a 10-tooth pinion to a rack. Any two gears with teeth of the same pitch and length laid out by this method will work satisfactorily with each other. The base of the odontograph table is a describing circle whose diameter is equal to the radius of the 12-tooth pinion; a gear laid out by its use will therefore work satisfactorily with any gear having the same pitch and general tooth dimensions, and with theoretical cycloidal curves constructed with a describing circle whose diameter is equal to the radius of the 12-tooth pinion.

60. Use of Grant's Cycloidal Odontograph Table. The first step in the use of the odontograph table is the location of the circles on which lie the centers of the arcs,



FIG. 11.

Fig. 11. These circles are concentric with the pitch circle, and their distances from it are determined in the following manner: In Table III, which is taken from Grant's "Treatise

TABLE III.

GRANT'S CYCLOIDAL ODONTOGRAPH TABLE.

No. of Teeth.	Divide by the Diametral Pitch.				Multiply by the Circular Pitch.			
	Faces.		Flanks.		Faces.		Flanks.	
	Rad. *C.*	Dis. *A.*	Rad. *D.*	Dis. *B.*	Rad. *C.*	Dis. *A.*	Rad. *D.*	Dis. *B.*
10	1.99	.02	−8.00	4.00	.62	.01	−2.55	1.27
11	2.00	.04	−11.50	6.50	.63	.01	−3.34	2.07
12	2.01	.06	∞	∞	.64	.02	∞	∞
13–14	2.04	.07	15.10	9.43	.65	.02	4.80	3.00
15–16	2.10	.09	7.86	3.46	.67	.03	2.50	1.10
17–18	2.14	.11	6.13	2.20	.68	.04	1.95	.70
19–21	2.20	.13	5.12	1.57	.70	.04	1.63	.50
22–24	2.26	.15	4.50	1.13	.72	.05	1.43	.36
25–29	2.33	.16	4.10	.96	.74	.05	1.30	.29
30–36	2.40	.19	3.80	.72	.76	.06	1.20	.23
37–48	2.48	.22	3.52	.63	.79	.07	1.12	.20
49–72	2.60	.25	3.33	.54	.83	.08	1.06	.17
73–144	2.83	.28	3.14	.44	.90	.09	1.00	.14
145–300	2.92	.31	3.00	.38	.93	.10	.95	.12
301 to Rack	2.96	.34	2.96	.34	.94	.11	.94	.11

on Gear-Wheels," are three sets of numbers, headed, respectively, Number of Teeth, Divide by the Diametral Pitch, and Multiply by the Circular Pitch. To find the distance *A* from the pitch circle at which to draw the line of face centers for a diametral-pitch gear with a given number of teeth, use the numbers in the column headed Diametral Pitch. Select from the column headed Dis. *A*, under the heading Faces, the number in the same horizontal line as the number corresponding to the number of teeth in the gear. This number divided by the diametral pitch gives the distance in inches from the pitch circle to the circle of face centers. The distance *B* from the pitch circle to the circle of flank centers is found by dividing the number in the column headed Dis. *B*, under the heading Flanks, corresponding to the number of teeth in the gear, by the diametral pitch.

The lengths of the radii *C* and *D* of the arcs forming the outlines of the faces and flanks of the teeth are found by dividing the numbers in the respective columns headed Rad. *C* and Rad. *D*, corresponding to the number of teeth, by the diametral pitch.

For a circular-pitch gear, the numbers headed Multiply by the Circular Pitch are to be used. The numbers are selected as in the diametral-pitch system, but the several distances and lengths of radii are found by multiplying the numbers in the table by the circular pitch.

61. Flanks for Gears Having 10 and 11 Teeth. The numbers in the table for the flank radii of gears having 10 and 11 teeth are preceded by the minus sign (−). This indicates that the direction of curvature of the flanks is opposite to that of the gears that have a larger number of teeth and that the centers from which the flanks are drawn must be taken on the opposite side of the tooth. The flanks of gears having a small number of teeth are convex; those having a larger number of teeth, concave.

The flanks for gears having 12 teeth are *radial*. This fact is indicated in the table by the symbol for infinity (∞) in the columns for length of flank radius and distance from pitch

circle to line of flank centers. To draw the flanks for these teeth draw a straight line from the pitch point toward the center of the pitch circle. Then draw a fillet from the point where this line touches the working-depth circle to the root circle.

62. The Willis Odontograph.—The Willis odontograph is a templet by means of which the radius of an approximate circular arc is obtained for drawing the outline of gear-teeth. The form of templet used for involute teeth

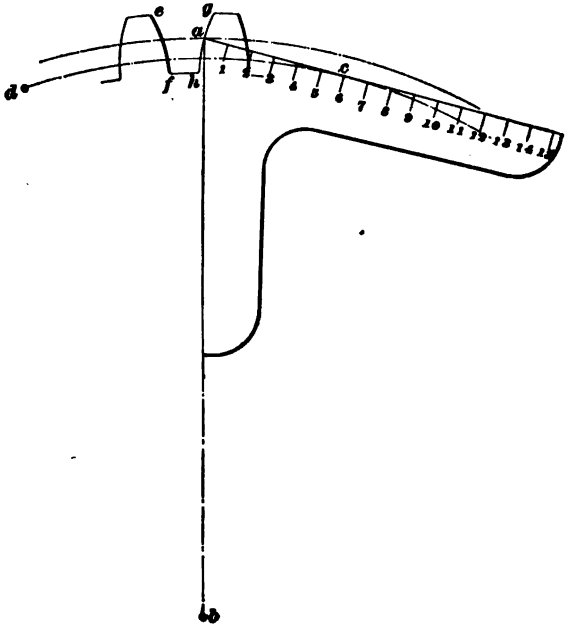


FIG. 12.

is shown in Fig. 12. The teeth are practically the same as those obtained by the single-arc involute system. The two sides of the odontograph make angles of 75° 30′ with each other. One side is divided into ¼-inch graduations marked from *1* to *15*. The blank side is placed along a radius with

the vertex *a* on the pitch circle. To find the radius of the tooth face, take as many of the ¼-inch divisions as there are inches in the radius of the pitch circle. If the radius of the pitch circle were 6 inches, it would give *a c* as the radius of the tooth face. The circle of centers shown dotted is drawn through the point *c* on the reduced scale with *b c* as a radius, and the tooth curves are drawn through the pitch points of the teeth previously located on the pitch circle. With *c* as a center the tooth curve *g h* is drawn, and with *d* as a center *e f* is drawn, giving us the outline of the tooth space. Having determined the circle of centers, the pitch points, and radius for tooth curves, the rest of the teeth can be readily drawn. A similar templet is made for drawing cycloidal teeth.

63. The Robinson Odontograph.—The Robinson odontograph is formed of two logarithmic spirals *a b* and *a c*, Fig. 13, one being the evolute of the other. They are used with a table prepared by Professor Robinson, and give a very accurate form of tooth outline. The part of the curve used is almost identical with the cycloid up to gears of 6-inch pitch.

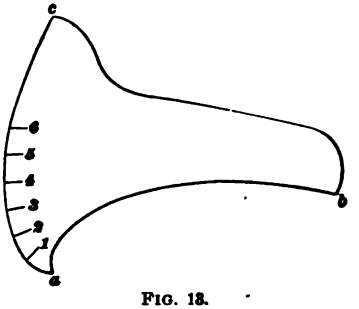


FIG. 13.

The templet is made so that it can be attached to a piece of thin board and when set for one tooth with the board centered on the center of the pitch circle, the templet can be turned to any desired position, and the outlines of other teeth drawn. In Fig. 14, *a* is the pitch point of the tooth and *b* is the middle point of the same tooth. The line *b c* is tangent to the pitch circle at *b* and the line *a d* is tangent to the pitch circle at *a*. From the table, a number is obtained that determines the number on the odontograph, which is to be placed at the pitch point *a*. The odontograph is moved around this point until the curve *e* is tangent to

the line bc. When in this position the face af of the tooth is drawn. The odontograph is then swung around the point a until the same curve becomes tangent to the line ad

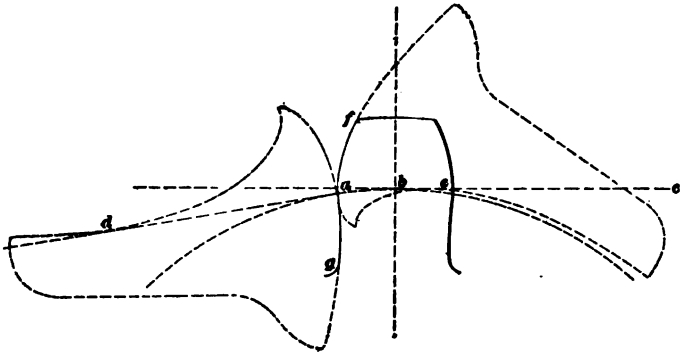


FIG. 14.

when the flank ag of the tooth is drawn. When one tooth curve has been formed the others are easily made by attaching the odontograph to a thin board fastened at the center of the gear, as already explained.

64. The Walker Odontograph Chart.—Mr. John Walker designed a system of curves for gear-teeth, for which he prepared a chart giving the information necessary for drawing the curves, thus reducing the labor of laying out the gear-teeth. This system is used in a number of shops manufacturing gearing and is considered by many the best and most convenient system for practical use. The form of tooth he uses is the epicycloidal for the face and epitrochoidal, or approximate hypocycloidal, for the flank. The tooth curves do not differ greatly from the regular cycloidal form already explained. By means of the chart, the thickness at the top, pitch line, and root of a tooth, and the radii of the face and of the flank can be determined at once, when the circular pitch and number of teeth of a gear are known.

BEVEL GEARS.

INTRODUCTION.

65. The teeth for the spur gear, rack, and internal gear are made on the same principles. They are all simply a modification of the spur gear. There are only two other forms of gears that are of sufficient importance to require explanation here; they are the *bevel gear* and the *worm-gear*.

Bevel gears are gears with pitch cones instead of pitch cylinders. The shafts are not parallel, but lie in the same plane.

The **miter gear** is a special case of bevel gear in which the shafts are at right angles and the gears have the same number of teeth and the same pitch diameter.



FIG. 15.

66. Rolling Cones. It has been explained that the motion of a pair of spur gears with correctly formed teeth is the same as that of two cylinders having diameters equal to the pitch diameters of the gears and rolling in contact with each other, without slipping. In a similar way, the motion of a pair of bevel gears is the same as that of a pair of cones rolling together, as shown in Fig. 15.

Fig. 16 represents a pair of bevel gears in which the rolling cones are in contact, so that if the teeth were continued all around the gears, the latter would be in mesh. The proportions of these gears are so chosen that their relative motion will be the same as that of the pair of rolling cones in Fig. 15. The relation between the gears and their corresponding cones is still further shown in Fig. 16 by the dotted outlines $O\,a\,b$ and $O\,b\,c$ of a pair of cones having the same dimensions as those in Fig. 15.

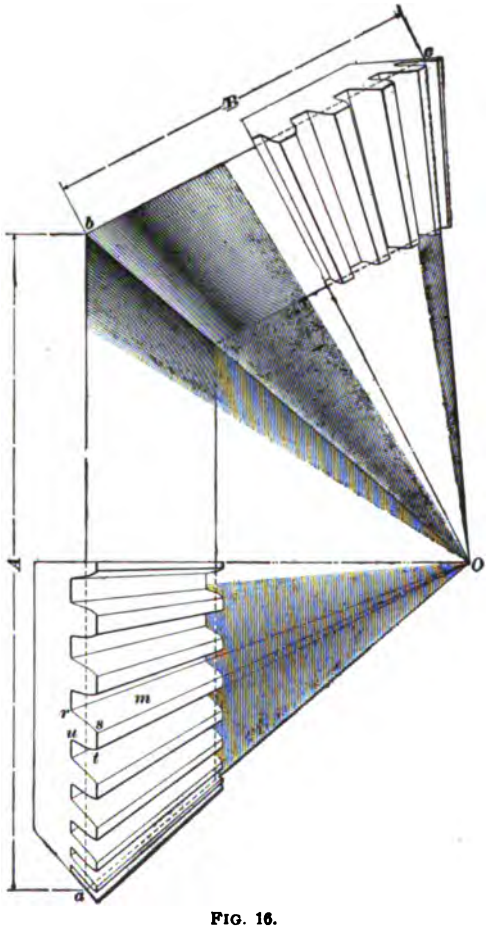


FIG. 16.

67. The Pitch Cones.—The cones whose relative motion corresponds to that of a pair of bevel gears are called the **pitch cones** of the gears. The *pitch circle* of a bevel gear is the circle represented by the base of its pitch cone. The *diameter* of a bevel gear is always understood to mean the diameter of its pitch circle; for example, the diameters A and B of the pair of gears shown in Fig. 16 are, respectively, the diameters $a\,b$ and $b\,c$ of the bases of the two pitch cones $O\,a\,b$ and $O\,b\,c$.

68. Convergence of Bevel-Gear Teeth.—In nearly all bevel gears found in practical use, the pitch cones have a common apex at the point of intersection of the center lines of the shafts connected by the gears, and the axes of the cones coincide with the center lines of these shafts. If the teeth of such gears are correctly formed, each tooth surface is made up of a series of straight lines, each of which passes through the point of intersection of the center lines of the shaft, or the common apex of the two pitch cones; the teeth of a bevel gear may therefore be conceived as having been cut out by a straight line that always passes through the apex of the pitch cone while it is moved in contact with the outlines of the bases of the teeth. For example, in Fig. 16, if we consider a straight line always passing through O while it is moved in contact with the outline $r\,s\,t\,u$ of the base of a correctly formed tooth, the line will coincide with the surface m of the tooth for every point of its motion. On account of this convergence of the surfaces of the teeth, and the consequent change in the size of the tooth curves, it is impossible to correctly form either side of the teeth by passing a formed cutter, which may be either a planing tool or a milling cutter, but once over the sides of each tooth.

69. Bevel-Gear Calculations. — The relations between the pitch diameters, pitch, numbers of teeth, and velocities of bevel gears are the same as the corresponding relations between the same features of spur gears; problems involving these relations may therefore be solved by an application of the rules for spur gears, remembering that the diameter of each of the bevel gears is that of the base of its pitch cone.

LAYING OUT BEVEL GEARS.

70. Laying Out Pitch Cones When the Shafts Are at Right Angles.—To lay out the pitch cones, first the center lines $o\,a$ and $o\,b$, Fig. 17 (a), of the shafts are drawn at right angles with each other. The next step depends on the velocity ratio, or on the relation between the diameters,

or the numbers of teeth of the two gears, and the conditions imposed on their diameters, or their distance from the point of intersection of the center lines of the shafts.

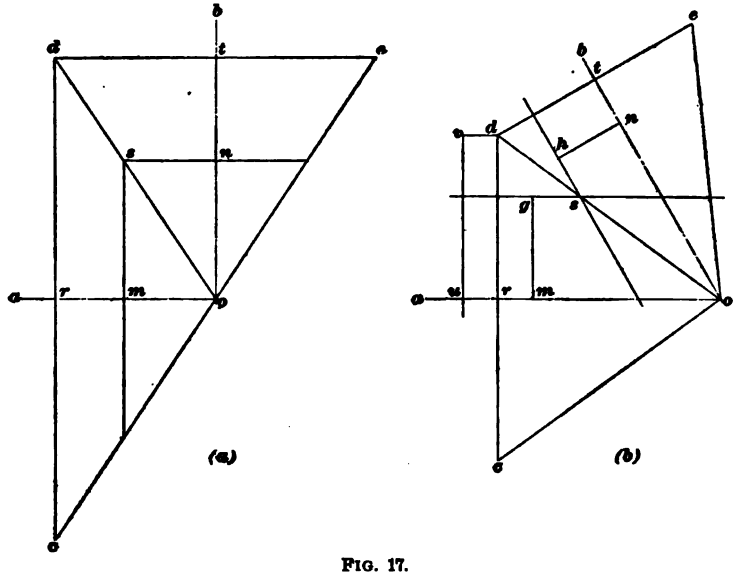


FIG. 17.

When the shafts are at right angles to each other, and the diameters of the gears are given, or can be calculated, the points r and t are obtained by laying off from the point of intersection o, Fig. 17 (a), a distance on each line equal to the radius of the gear on the other shaft. Through the points r and t so obtained, the perpendiculars $c\,d$ and $e\,d$ are drawn intersecting in d. Then laying off $r\,c$ and $t\,e$ equal, respectively, to $r\,d$ and $t\,d$ and drawing the lines $o\,c$, $o\,d$, and $o\,e$, the outlines of the pitch cones $o\,c\,d$ and $o\,d\,e$ are completed. The angles $c\,o\,a$ or $d\,o\,a$, and $e\,o\,b$ or $d\,o\,b$, are called the center angles of their respective cones.

EXAMPLE.—Lay out the center angles of a pair of bevel gears for the shafts whose center lines are $o\,a$ and $o\,b$, Fig. 17 (a). The gears are to have 48 and 32 teeth, respectively, and the angle between the center lines is 90°.

SOLUTION.—Since the sizes of the gears are proportional to the number of teeth in them, and the gear on the shaft $o\,a$ is to have 48 teeth,

while that on $o\,b$ has 32, the distances to be laid off must be, respectively, 32 and 48 divisions on some convenient scale. Therefore by laying off on $o\,a$ a distance $o\,m$ equal to 32 divisions and on $o\,b$ a distance $o\,n$ equal to 48 divisions, the points m and n are obtained through which the lines $m\,s$ and $n\,s$ can be drawn perpendicular, respectively, to the center lines $o\,a$ and $o\,b$. By drawing the line $o\,s$ through the point of intersection s of these perpendiculars and the point of intersection o of the center lines, the center angles $a\,o\,s$ and $b\,o\,s$ of the pitch cones are obtained. Ans.

71. Laying Out Pitch Cones When the Shafts Are Not at Right Angles.—The center lines of the shafts are laid out, as $o\,a$ and $o\,b$, Fig. 17 (b), at the given angle between the shafts, and any convenient distances, as $o\,m$ and $o\,n$, are laid off on them. Through the points m and n so obtained, lines are drawn perpendicular to the center lines of the shafts, as $m\,g$ and $n\,h$, that are proportional either to the velocity of the gear on the other shaft or to the diameter or number of teeth of the gear on the shaft from whose center line the perpendicular is drawn. Then through the points g and h on these perpendiculars draw lines parallel to the center lines until they intersect each other. The line $o\,s$ drawn through the point of intersection s of these parallels and the point of intersection o of the center lines of the shafts, fixes the center angles $d\,o\,a$ and $d\,o\,b$ of the gears.

When the distance from the point of intersection of the center lines to the base of one of the cones is fixed the completion of the cones is accomplished by laying off the given distance, as $o\,r$, Fig. 17 (b), on its proper center line. Through the point r draw the line $c\,d$ perpendicular to $o\,a$, extending it until it intersects the line $o\,s$ in d, and lay off $r\,c$ equal to $r\,d$. Through d draw the line $d\,e$ perpendicular to $o\,b$ and make $t\,e$ equal to $t\,d$. Draw $c\,o$ and $e\,o$. The outlines of the two pitch cones are then $c\,o\,d$ and $d\,o\,e$, respectively, and the pitch diameters of the two gears are $c\,d$ and $d\,e$.

When the diameter of one or both of the gears is fixed, the pitch cones may be laid out by the other method illustrated in Fig. 17 (b). First, the contact line $o\,s$ is laid out by the method explained; then, from any convenient point, as u, on the center line of the gear whose diameter is given,

a perpendicular $u\,v$ is drawn and on it the distance $u\,v$ is laid off equal to the radius of the gear. Through v, a line $v\,d$ is drawn parallel to $o\,a$ until it intersects the contact line $o\,s$ in d. The point d will be one extremity of the pitch lines of the gears. From d, the lines $d\,c$ and $d\,e$ are drawn perpendicular, respectively, to the axes $o\,a$ and $o\,b$, making the distances $r\,c$ and $t\,e$ equal, respectively, to $r\,d$ and $t\,d$; from the points c and e the lines $c\,o$ and $e\,o$ are drawn. The outlines of the pitch cones are $c\,o\,d$ and $d\,o\,e$.

72. Laying Out Bevel-Gear Blanks.—The method of laying out the blanks for a pair of bevel gears is illustrated in Fig. 18. First the pitch cones $o\,c\,d$ and $o\,d\,e$ are constructed. On the lines $c\,o$, $d\,o$, and $e\,o$ the distances $c\,c'$, $d\,d'$ and $e\,e'$ are laid off, each being equal to the length of the face of the required teeth. Through the points c and c', d and d', e and e', representing the ends of the teeth, lines are drawn perpendicular to the lines $o\,c$, $o\,d$, and $o\,e$ on which these points are located. By producing the lines through d and d' until they intersect the center lines $o\,a$ and $o\,b$, the points f, g, f' and g' are located.

On the perpendicular through the point c, the distances $c\,h'$, $c\,j'$, and $i'\,j'$ are laid off equal, respectively, to the addendum, root, and the clearance of the required teeth, calculating these values from the pitch, and remembering that the pitch diameter is the diameter $c\,d$ of the base of the pitch cone. Similarly, the distances $d\,h$, $d\,j$, and $i\,j$ are laid off representing the addendum, root, and clearance of the tooth of the gear A, and the corresponding distances $d\,i$, $d\,k$, and $h\,k$, $e\,i''$, $e\,k''$, and $h''\,k''$ of the teeth of the pinion B. From each of the points so determined, a line to the point o is drawn; those parts of these lines included between the perpendiculars through the points representing the ends of the teeth give the outlines of the teeth, and fix the outside diameters $h\,h'$ and $i\,i''$ of the blanks.

The angles $o\,u\,a$ and $o\,v\,b$ are the face angles and $l'\,c\,a$ and $l''\,c\,b$ are the edge angles. These angles are used in turning up the blanks preparatory to cutting the teeth. In some cases it may be more convenient while turning up the

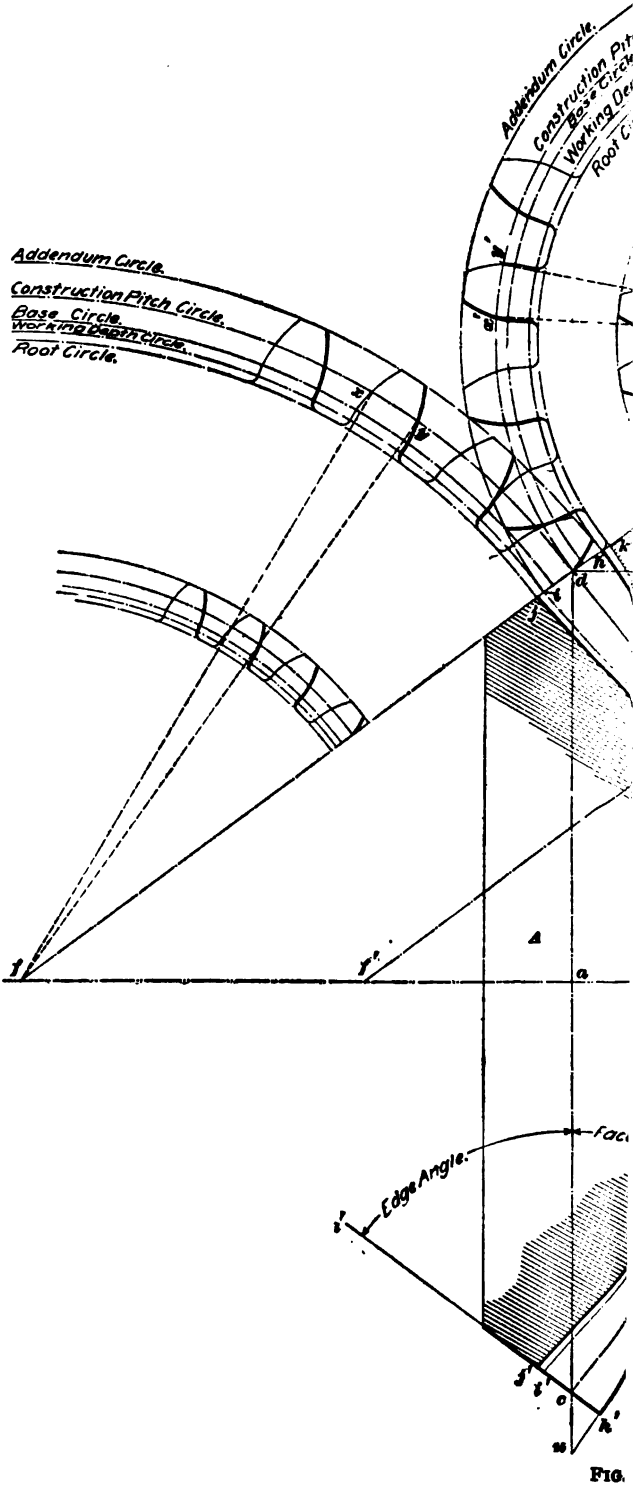

Addendum Circle.
Construction Pitch Circle.
Base Circle.
Working Depth Circle.
Root Circle.
Edge Angle.

FIG.

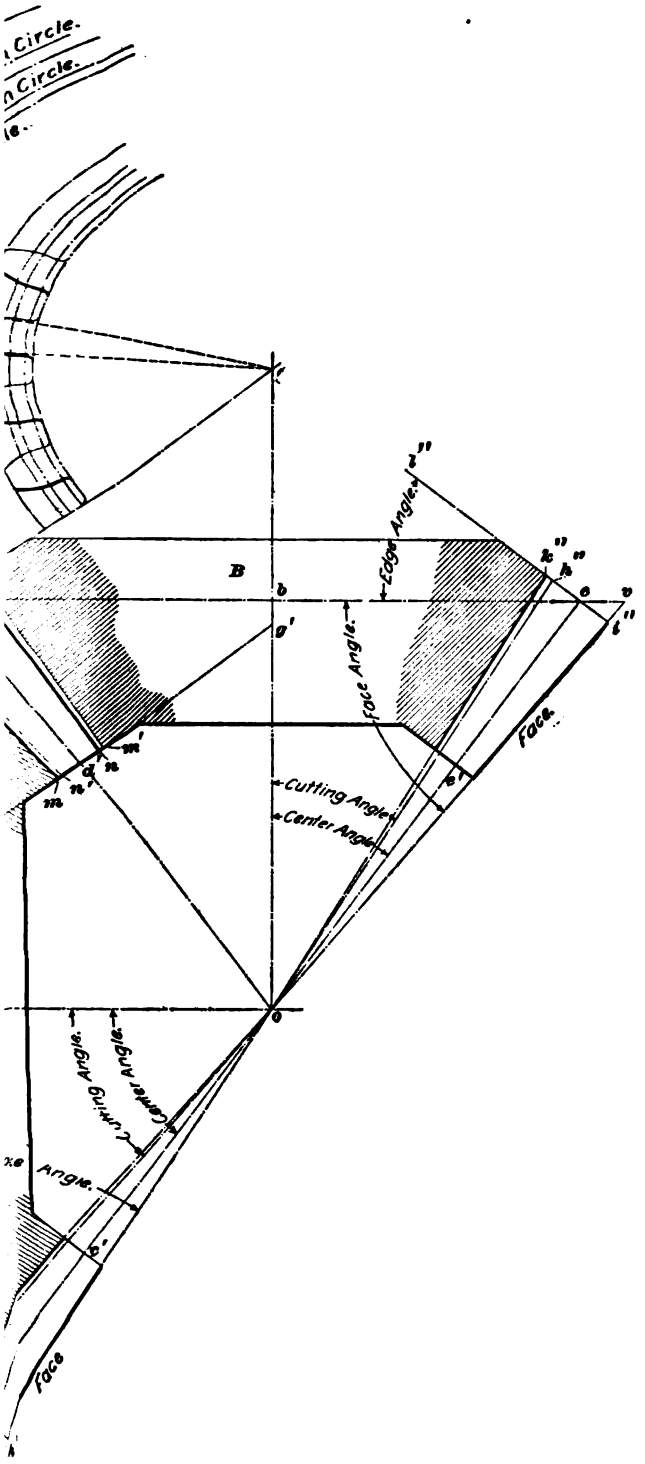

Circle.
Circle.
B
Edge Angle.
Face Angle.
Face.
Cutting Angle.
Center Angle.
Angle.
face

FIG. 18.

blanks to work from the angles $h'oa$ and $i''ob$; when the face angles are given, these angles may be found by subtracting the corresponding face angles from 90°. The cutting angles $i'oa$ and $h''ob$ are used for setting the blank when the teeth are to be cut in the milling machine. When the gears are to be cut by planing, the angles $j'oa$ and bok'' are taken as the cutting angles. Since the lines $l'h'$ and $l''i''$ are, respectively, perpendicular to the lines oc and oe, the edge angles $l'ca$ and $l''eb$ are, respectively, equal to the center angles coa and eob.

73. Determining the Angles and Diameters of the Blanks.—The edge, face, cutting, and center angles are generally determined by measuring the drawing with a protractor. It is seldom practicable to set the milling machine or gear-cutter to angles smaller than $\frac{1}{4}$ degree, or 15′; it is therefore useless, in most cases, to attempt to measure the angles on the drawing to a greater degree of precision.

The outside diameters of the blanks may generally be determined with a sufficient degree of accuracy by measuring from a carefully made drawing like that of Fig. 18. It is better, however, to have this diameter carefully computed in the drawing room and the dimension placed upon the drawing.

74. Laying Out Tooth Curves.—Having the pitch cones and the side outlines of the teeth laid out, Fig. 18, arcs of circles are drawn with radii equal to the distances fj, fi, fd, and fh; and gk, gh, gd, and gi about f and g, as centers, to represent the roots, working depths, pitch circles, and addenda of the teeth at the larger end. These arcs are on the drawing on which the blanks are laid out, but, if desirable, they may be made on separate sheets. They are used in laying out the tooth curves in the same manner as the similar circles for spur gears are used.

In explaining the use of these arcs for laying out the teeth, the circle, of which the arc representing the pitch circle forms a part, will be called the *construction pitch circle*, as designated on the drawing, Fig. 18, to distinguish it from the actual pitch circle of the gear. The same reasoning would hold

for all the other circles but they are not so marked. The surface on which the large ends of the teeth are placed is a cone, which if rolled out into a plane, that is if the cone were developed, the addendum circle, pitch circle, base circle working-depth circle, and root circle would roll out into the curves shown in Fig. 18.

Inasmuch as it is not practicable to construct cones and lay out teeth on them, it has become the custom to lay out the developed teeth on these construction lines. They differ slightly from the actual teeth but not enough to necessitate a different method for their laying out.

To lay out the curves for the larger ends, lay off on the construction pitch circle spaces equal to the circular pitch. The length of these spaces is found by dividing the circumference of the pitch circle of the gear by the number of teeth. Divide each space into two parts to represent, respectively, the thickness of the tooth and the width of the space, thus obtaining the pitch points of the teeth. The tooth curves are then to be drawn through these pitch points.

75. Tooth Curves by Odontograph Table.—When the involute system of teeth is used, the distance from the construction pitch circle at which to draw the base circle is to be calculated from the diameter of the construction pitch circle. In using the involute or the cycloidal odontograph table, the number of teeth to be used in selecting from the table the factor for calculating the face and flank radii, or the distances from the pitch circle to the lines of face and flank centers, is the number found by dividing the circumference of the construction pitch circle by the circular pitch; in other words, instead of using the actual number of teeth in the gear, use the number of teeth there would be in a gear having the required pitch and a diameter equal to that of the construction pitch circle. In dividing the circumference of the construction pitch circle by the circular pitch, the result will rarely be a whole number and hence the nearest whole number is taken.

To draw the outlines of the inner ends of the teeth, a set of arcs is drawn similar to those drawn for the outer ends,

using radii equal to the distances $f'm$, $f'n'$, $f'd'$, and $f'n$, or $g'm'$, $g'n$, $g'd'$, and $g'n'$, and laying out the teeth on these arcs in accordance with the general method used for the outer ends. It will generally be better to draw these arcs with the same centers with which the arcs for the outer ends were drawn, as shown in Fig. 18. Instead of calculating the pitch for the inner ends, a convenient method of locating the pitch points is to draw lines from the centers to the pitch points of the outer ends, as shown by the dotted lines fx, fy, gx', and gy'. The points where these lines intersect the construction pitch circles for the inner ends of the teeth will be the pitch points through which to draw the curves for the outlines of the inner ends.

WORM-WHEELS AND WORMS.

KINDS OF WORM-WHEELS.

76. Description of Worm and Worm-Wheel.—A worm and worm-wheel are a combination of machine elements composed of a screw and a gear that is used for transmitting motion from one shaft to another at right angles to each other when the shafts are not in the same plane. It is especially adapted to transmission when it is desired to change small pressure at high speed to high pressure at low speed. The worm, as a reference to Fig. 19 will show, is simply a screw whose threads fit the teeth of the worm-wheel.



FIG. 19.

A **worm** is a screw with a thread of such a form that its cross-section is the same as that of a gear-tooth or a tooth,

the worm being intended to mesh with a special form of spur gear called a worm-wheel.

A **worm-wheel** is a gear with which a worm meshes. Worm-wheels may be plain spur gears with their teeth cut at an angle, or they may be special spur gears made to fit the worm-thread accurately.

In practice, a worm-wheel is made in one of the three different ways shown in Fig. 20. In (*a*) the teeth are

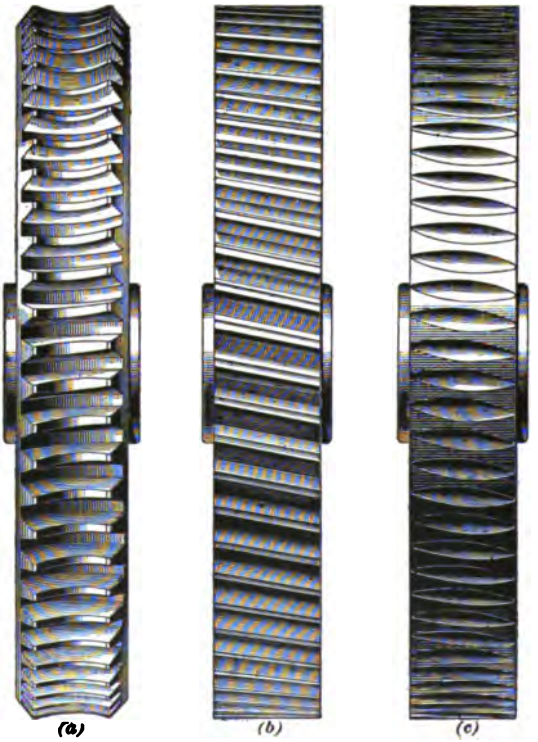


FIG. 20.

curved to fit the worm; such a wheel is cut with a hob, and is, hence, called a **hobbed worm-wheel.** The tool, or hob, used for cutting this wheel is practically a duplicate of the worm, except that the outside diameter of the hob is slightly greater than that of the worm, to allow for clearance. The

worm will fit the worm-wheel if the cutting is carefully done, and the contact between the worm and worm-wheel will be all that can be desired. A hobbed worm-wheel should always be used if much power is to be transmitted, as it will outlast either of the gears shown in Fig. 20 (*b*) and (*c*).

77. In Fig. 20 (*b*), the wheel is seen to have straight teeth cut at an angle to the axis; this angle is made to suit the angle of the helix of the worm. Obviously, the contact of the threads of the worm with the teeth of such a worm-wheel is rather imperfect; since this kind of a worm-wheel can be cut with an ordinary standard gear-cutter at an expense but slightly in excess of that of a spur gear, it is much used for light work. The worm-wheel with straight teeth at an angle to the axis is designed by the same rules as a spur gear; the angle that the teeth make with the axis is determined by trial in cutting it.

Fig. 20 (*c*) shows a form of worm-wheel that is occasionally used on gear-cutting engines where a man has to take hold of the gear and turn it by hand. One advantage these teeth possess is that they are so protected as to be less liable to injury than those shown in Fig. 20 (*a*) and (*b*).

The outside diameter of a worm-wheel of this kind may be the same as that of the spur wheel having the same pitch and number of teeth. For ordinary work, the notches are frequently cut with a fly cutter set to a radius slightly larger than that corresponding to the outside diameter of the worm. If a standard cutter of the right pitch and diameter is available, it should be used in preference to the fly cutter. Nothing is to be gained by curving the face of the wheel to suit the worm when a worm-wheel of the kind shown in Fig. 20 (*c*) is not to be finished by hobbing. Worm-wheels of this kind are frequently very carefully and accurately made and used in graduating machines or dividing engines. Worm-wheels of this kind may also be finished by hobbing, but the hob is not sunk into the wheel to as great a depth as in the wheel shown in Fig. 20 (*a*).

WORM-WHEEL CALCULATIONS.

78. Velocity Ratio of Worm-Wheels.—The number of teeth that a worm-wheel must have to produce a given velocity ratio is found as follows:

Rule.—*Multiply the number of revolutions that the worm is to make for one revolution of the worm-wheel by the number of threads of the worm.*

EXAMPLE 1.—If a single-threaded worm is to make 56 revolutions in order to revolve the worm-wheel once, how many teeth should the latter have?

SOLUTION.—Applying the rule just given, we get $56 \times 1 = 56$. Ans.

EXAMPLE 2.—If a triple-threaded worm is to make 24 revolutions in order to revolve the worm-wheel once, how many teeth should the latter have?

SOLUTION.—Applying the rule, we get $24 \times 3 = 72$. Ans.

79. Worm-Wheel With 30 or More Teeth.—To design a worm-wheel that is to be hobbed and has 30 or

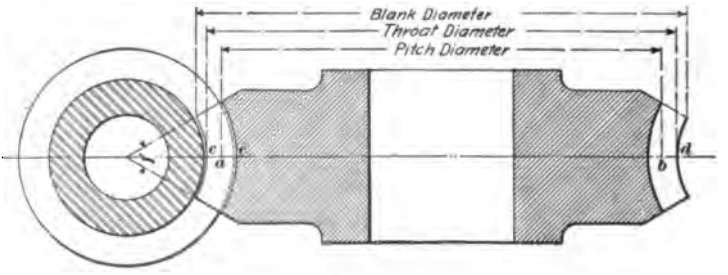


FIG. 21.

more teeth, first of all calculate the pitch diameter *a b*, Fig. 21, as follows:

Rule.—*Multiply the number of teeth by the distance between centers of adjacent threads of the worm and divide the product by 3.1416.*

Observe that in the case of a single-threaded worm, the distance between centers of adjacent threads is equal to the amount the thread advances in 1 revolution, or the **lead** of the thread. In the case of a multiple-threaded worm, the

distance between centers of adjacent threads is the lead divided by the number of threads.

EXAMPLE.—Calculate the pitch diameter of a worm-wheel having 42 teeth for a double-threaded worm having a lead of 1 inch.

SOLUTION.—The distance between centers of adjacent threads of the worm is $1 \div 2 = .5$ in. Applying the rule, we get

$$\frac{42 \times .5}{3.1416} = 6.684 \text{ in.} \quad \text{Ans.}$$

80. Throat Diameter of a Worm-Wheel.—The throat diameter of the worm-wheel, as *c d*, Fig. 21, is calculated as follows:

Rule.—*Divide twice the pitch diameter by the number of teeth and add the quotient to the pitch diameter.*

EXAMPLE.—Taking the example last given, what should be the throat diameter?

SOLUTION.—Applying the rule, we get

$$6.684 + \frac{6.684 \times 2}{42} = 7.002 \text{ in.} \quad \text{Ans.}$$

81. Depth of Tooth of a Worm-Wheel.—In accordance with Brown & Sharpe practice, the depth *c e* of the tooth is calculated by the following rule:

Rule.—*Multiply the distance between centers of adjacent threads of the worm by .6866.*

EXAMPLE.—Taking the last example again, what should be the depth of the teeth?

SOLUTION.—The distance between centers of adjacent threads of the worm is .5 in. Applying the rule just given, we have

$$.5 \times .6866 = .3433 \text{ in.} \quad \text{Ans.}$$

The diameter of the blank is most conveniently obtained by measuring a scale drawing of the worm-wheel. The angle *f* may be made from 60° to 90°.

82. Worm-Wheel With Less Than 30 Teeth. When the worm-wheel has less than 30 teeth, calculate the

pitch diameter by the rule given in Art. **79**, and the depth of the teeth by the rule given in Art. **81**; the throat diameter is, however, to be calculated by the following rule:

Rule.—*Multiply the product of the distance between centers of adjacent threads of the worm and the number of teeth of the worm-wheel by .298. Add to it 1.273 times the distance between centers of adjacent threads of the worm.*

EXAMPLE.—Find the throat diameter for a worm-wheel with 24 teeth meshing with a single-threaded worm having a lead of .75 inch.

SOLUTION.—Since the worm is single-threaded, the distance between centers of adjacent threads is .75 in. Applying the rule, we get

$$.75 \times 24 \times .298 + 1.273 \times .75 = 6.319 \text{ in.} \quad \text{Ans.}$$

WORM-CALCULATIONS.

83. Pitch Diameter of a Worm. — The velocity ratio of a worm and worm-wheel is independent of the relative pitch diameters of the worm-wheel and worm, from which fact it follows that in designing a worm and worm-wheel for a given distance between centers, we have the choice of many different designs. One good method of procedure when the distance between centers is given, is to choose some convenient lead of thread for the worm that can be cut readily in an engine lathe. The lead, or pitch, of the worm-thread divided by the number of threads on the worm will give the pitch of the teeth for the worm-wheel. From this, compute the pitch diameter of the worm-wheel. Subtract half the pitch diameter of the worm-wheel from the distance between centers and double the remainder, in order to obtain the pitch diameter of the worm. If a comparison of the pitch diameter of the worm with the pitch diameter of the worm-wheel shows the former to be larger than is considered desirable, choose a coarser thread for the worm and again compute the pitch diameters. Repeat this series of operations until the ratio of the two pitch diameters is considered to be about right.

84. Outside Diameter of Worm.—The pitch diameter a of the worm, as represented by the lines bc and de,

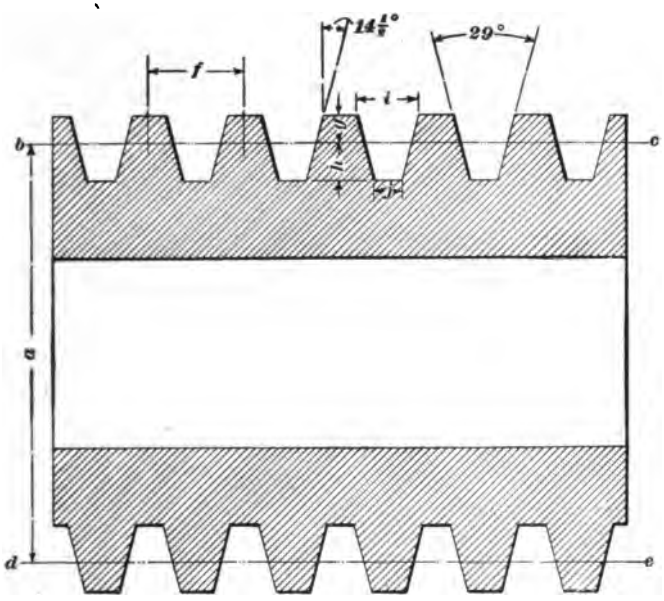


FIG. 22.

Fig. 22, should always be computed as stated in Art. **83.** When the worm-wheel has 30 or more teeth, calculate the outside diameter as follows:

Rule.—*Multiply the distance f between centers of adjacent threads of the worm by .6366 and add the product to the pitch diameter of the worm.*

EXAMPLE.—A triple-threaded worm is to have a pitch diameter of 3 inches and a lead of thread of 1.5 inches. What should be the diameter of the blank for the worm?

SOLUTION.—Since the worm is triple-threaded, the distance between centers of adjacent threads is $1.5 \div 3 = .5$ in. Applying the rule just given, we get

$$3 + .5 \times .6366 = 3.318 \text{ in.} \quad \text{Ans.}$$

The total depth $g + h$ of the worm-thread is equal to the depth of tooth of the worm-wheel, and is, hence, to be calculated by the rule given in Art. **81.**

85. Worm-Thread.—The width *i*, Fig. 22, of the space between threads at the top is to be calculated as follows:

Rule.—*Multiply the distance between centers of adjacent threads by .665.*

EXAMPLE.—Taking the same worm as in the example in Art. **84**, what should be the width of the thread at the top?

SOLUTION.—Applying the rule, we get

$$.5 \times .665 = .333 \text{ in.} \quad \text{Ans.}$$

86. The width *j*, Fig. 22, of the bottom of the space between the threads is to be found as follows:

Rule.—*Multiply the distance between centers of adjacent threads of the worm by .31.*

EXAMPLE.—Calculate the width of the space between threads of the worm mentioned in the example given in Art. **84.**

SOLUTION.—Applying the rule just given, we get

$$.5 \times .31 = .155 \text{ in.} \quad \text{Ans.}$$

If the dimensions of the space between the threads are calculated by the rules given here and in Arts. **81, 85,** and **86,** the angle between the sides of the thread will be almost exactly 29°, which is the standard angle for worm-threads that has been almost universally adopted.

87. Worm for Worm-Wheel With Less than 30 Teeth.—The outside diameter of a worm intended for a worm-wheel having less than 30 teeth and having a throat diameter made in accordance with the rule given in Art. **82,** and a depth of tooth made in accordance with the rule given in Art. **81,** may be calculated as follows:

Rule.—*Multiply the number of teeth of the worm-wheel by the distance between centers of adjacent threads of the worm, and multiply the product by .149. Subtract the last product from the distance between centers of the worm and worm-wheel, and multiply the remainder by 2.*

EXAMPLE.—The distance between centers of a worm and worm-wheel is 3 inches. The worm-wheel has 24 teeth, and the worm is single-threaded with a lead of thread of .5 inch. What should be the outside diameter of the blank for the worm?

SOLUTION.—Applying the rule just given, we get

$$2 \times (3 - 24 \times .5 \times .149) = 2.424 \text{ in.} \quad \text{Ans.}$$

The outside diameter of the blank for the worm having been calculated by the preceding rule, the space between the threads of the worm is to be made according to the rules given in Arts. **81, 85,** and **86.**

GEAR-CUTTING.

SYSTEMS AND PROCESSES.

SYSTEMS.

1. There are two general systems of forming gear-teeth by cutting operations, which may be called the *duplication* and the *generation* systems.

2. In the **duplication** system, the cutting tool either has a profile corresponding to the shape of the space between two gear-teeth, or it has a cutting point, or edge, that is guided by a templet. In either case, the cutting tool merely *duplicates* a tooth outline, but does not *generate* one. From this it follows that under the duplication system the correctness of the tooth curves depends primarily on the degree of accuracy within which the profile of the cutting tool or of the templet represents the true tooth curve. This consideration involves a duplication of any errors that may exist in the cutter, or a reproduction to a reduced scale of any errors of the templet.

3. The **generation** system will, in general, produce more accurate tooth curves than the duplication system. As implied by the name, the tooth curves are generated mechanically for each tooth; in consequence, the errors are very small.

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METHODS AND PROCESSES.

4. In each system of gear-cutting there is a number of different processes by means of which gear-teeth may be formed; the processes most commonly used are here briefly explained.

5. There are two distinct and radically different processes in the duplication system, both of which are used in practice. Incidentally, it may be remarked that at present the duplication system is the one in most general use. The two processes in that system are called the *formed-cutter process* and the *templet-planing process.*

FORMED-CUTTER PROCESS.

6. In the **formed-cutter process,** a rotary cutter (a formed milling cutter) or a planer tool having a profile equal to the space between two teeth is used for milling or planing out the spaces, thus reproducing its own profile within a reasonable limit of variation. In this process, the gear blank remains stationary while a space is being cut; that is, it does not revolve about its axis during the cutting operation. Upon the completion of each space, the blank is revolved the proper part of a revolution, which is measured or obtained by the aid of some suitable indexing mechanism. On the whole, it will be found that the best work can be done with a formed milling cutter, which not only will work faster, but, also, by reason of its numerous cutting edges and its peculiar formation, will preserve its profile much longer than the planing tool with its single cutting edge.

7. The formed-cutter process, in which a formed milling cutter is employed, is at present the one in most extensive use for the cutting of spur gears and sprocket wheels; it is also largely used for bevel gears, although, by reason of the tooth profile changing in size throughout the length of the face of a bevel gear, the formed-cutter process can, at its best, produce only an approximately correct bevel gear.

8. The use of a formed planing tool is inadvisable when conditions permit a formed milling cutter to be employed; the planing tool is convenient, however, for some work, and allows a machine like a slotter, a key seater, a shaper, or a planer to be used for work beyond the range of a milling machine or gear-cutting machine, and in isolated cases will allow gears to be cut when no machine fitted for a rotary cutter is available.

TEMPLET-PLANING PROCESS.

9. In the **templet-planing process,** a round pointed planing tool is guided by a properly shaped templet through the intervention of suitable mechanism, and copies the profile given by the templet either to the same scale or to a reduced scale. This process is chiefly used for planing the teeth of bevel gears and miter gears, and involves the use of a special machine. The teeth of spur gears and sprocket wheels can be cut with the templet-planing process, but not as fast as with the formed-cutter process.

CONJUGATE-TOOTH METHOD.

10. There is but one method of generating correct tooth curves that has come into practical use. When a gear-tooth cutter operates on a gear blank generating teeth, while the cutter and blank roll together without slipping, then the teeth formed on the blank are conjugate to the teeth of the cutter. All gears generated with the same cutter by this process are conjugate to the cutter and to each other. Gears made in this way are generated by the conjugate-tooth method, and will roll on each other without slipping, that is, the velocity ratio is constant.

11. Molding-Planing Process.—Rotary cutters or planing tools formed to the profile of a gear-tooth having the correct size may be used for generating conjugate teeth

on a gear blank. In order to form these teeth in one process, a planing tool is made in the form of a gear-wheel, and is reciprocated past the gear blank, to which it is connected in such a manner that the cutter and blank will turn together about their axes as if they were a gear and pinion meshing together. The rotation takes place when the pinion acting as a cutter is clear of the blank.

12. This process of generating conjugate teeth is technically known as the **molding-planing process**; while it is an old and fairly well-known process, it has come into practical use but very recently. Its introduction is due to the Fellows Gear Shaper Company, of Springfield, Vermont, who have succeeded in devising mechanical means of making for this purpose hardened-steel cutters with a degree of accuracy so great that the errors in the tooth curves of the cutter are practically insensible. The process is very well adapted for spur gears, sprocket wheels, and internal gears, but has at present not been extended to screw gears. It is claimed that not only will the teeth be more correctly formed by this process, but that gears can also be cut at less cost than by any other process.

13. Single-Tooth Molding-Planing Process.— There is one process of forming conjugate teeth by planing in which a single-tooth planing tool is used; from this fact it is called the **single-tooth molding-planing process.** It is used in practice for originating the tooth curves of bevel gears, and will be explained in detail farther on.

14. Molding-Milling Process.—A series of rotary cutters placed alongside each other and having a longitudinal section equal to that of a rack of the same pitch as the gear to be cut, may be used for generating gear-teeth conjugate to those of the rack whose section is represented by the cutter. Gears having different numbers of teeth thus formed will run together correctly; for, since any gears thus formed have teeth conjugate to the rack, it follows that the teeth of any two gears are also conjugate to each other. The cutters are given an axial motion equivalent

to that of a rack, and after passing clear around the gear blank are traversed a little over its face; the gear blank is positively rotated just as if it were in mesh with the generating rack, and, in consequence, gear-teeth conjugate to those of the rack are generated. This process may be called the **molding-milling process**; it has been put into practical use in a modified form by Mr. Ambrose Swasey, of the firm of Warner & Swasey, Cleveland, Ohio.

15. Hobbing Process.—There is one case of generating conjugate teeth by a rotary cutter that is in general use. This case is the making of accurate worm-wheels by hobbing; the hob is a special form of a rotary cutter, and produces teeth conjugate to those of a worm.

DUPLICATION SYSTEM.

FORMED-CUTTER PROCESS.

INTRODUCTION.

16. When a planing tool is to be used for cutting gear-teeth, the exact tooth form of opposite sides of two adjacent teeth is laid out on a piece of sheet metal, as sheet zinc, and a templet is then formed to which the planing tool is fitted.

Milling cutters for all the standard diametral pitches in use can be obtained from manufacturers making a specialty of this work. Such cutters are made by the use of special machinery, and are so accurately and cheaply made that it does not pay any one, as a general rule, to make them himself.

STANDARD CUTTERS.

17. While, correctly speaking, there should be a differently shaped cutter for every number of teeth in a gear of the same pitch, it has been shown practically that the

TABLE OF STANDARD CUTTERS.

Epicycloidal.				Involute.	
Pratt & Whitney.		Brown & Sharpe.			
Designating Mark of Cutter.	Number of Teeth of Gear.	Designating Mark of Cutter.	Number of Teeth of Gear.	Designating Mark of Cutter.	Number of Teeth of Gear.
1	12	A	12	1	135 to rack
2	13	B	13	2	55–134
3	14	C	14	3	35–54
4	15	D	15	4	26–34
5	16	E	16	5	21–25
6	17	F	17	6	17–20
7	18	G	18	7	14–16
8	19	H	19	8	12–13
9	20	I	20		
10	21–22	J	21–22		
11	23–24	K	23–24		
12	25–26	L	25–26		
13	27–29	M	27–29		
14	30–33	N	30–33		
15	34–37	O	34–37		
16	38–42	P	38–42		
17	43–49	Q	43–49		
18	50–59	R	50–59		
19	60–75	S	60–74		
20	76–99	T	75–99		
21	100–149	U	100–149		
22	150–299	V	150–249		
23	300 and over	W	250 and over		
24	Rack	X	Rack		

divergence of the tooth curves is so gradual that one cutter may be made to answer for several numbers of teeth without introducing any serious error.

In the cycloidal system of gearing there are 24 cutters in a set for each diametral pitch. Incidentally, it may be remarked that the cycloidal system is commonly miscalled the *epicycloidal* system; in fact, all manufacturers stamp cutters intended for the cycloidal-tooth form "Epicycloidal," and refer to them by that name. In the involute system of gearing there are 8 cutters in a set. A set of cutters comprises all the cutters required for gears above 12 teeth up to and including the rack, and will cut gears that are interchangeable. The different cutters of each set are designated by the different makers by letters or figures; the accompanying Table of Standard Cutters gives the designating marks and the number of teeth of the gear for which the cutter can be used. For instance, by referring to the table it is seen that a number 21 Pratt & Whitney epicycloidal cutter is intended for gears having from 100 to 149 teeth, inclusive of both numbers, and a Brown & Sharpe epicycloidal cutter designated by the letter S is intended for gears having from 60 to 74 teeth, inclusive of both. Likewise, a number 2 involute cutter is intended for gears having between 55 and 134 teeth, inclusive of both.

STANDARD PITCHES.

18. The standard diametral pitches that Pratt & Whitney make epicycloidal cutters for are as follows: 1½, 2, 2½, 3, 3½, 4, 5, 6, 7, 8, 9, 10.

The standard diametral pitches that Brown & Sharpe make epicycloidal cutters for are as follows: 3, 4, 5, 6, 8, 10.

On a special order, Brown & Sharpe furnish the following pitches for epicycloidal cutters: 2, 2¼, 2½, 2¾, 3½, 7, 9, 12, 14, 16.

Involute cutters can be obtained on regular order for the

following diametral pitches: 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 36, 40, 48.

On special order, Brown & Sharpe will furnish involute cutters for the following diametral pitches: 2, 2¼, 2½, 2¾, 3¼, 3½, 3¾, 4½, 5½, 13, 15, 38, 44, 50, 56, 60, 64, 70, 80, 120.

Cutters for other pitches can usually be furnished by manufacturers to order, but naturally only at an advance in price. Neither epicycloidal nor involute cutters are regularly in the market for gears designed on the circular-pitch system; such cutters can be obtained only on special order at a proportionate advance in price.

DEPTH OF CUT.

19. Calculating the Depth.—The correct depth of cut for standard epicycloidal and involute cutters made according to the Brown & Sharpe system is calculated as follows:

Rule.—*Divide 2.157 by the diametral pitch.*

EXAMPLE.—Find the proper depth of cut for a 2-pitch Brown & Sharpe cutter.

SOLUTION.—Applying the rule just given, we get

$$\frac{2.157}{2} = 1.078 \text{ in., nearly.} \quad \text{Ans.}$$

20. For epicycloidal cutters made by Pratt & Whitney, the correct depth of cut is obtained as follows:

Rule.—*Divide 2.125 by the diametral pitch.*

EXAMPLE.—Find the depth of cut of a standard 6-pitch Pratt & Whitney epicycloidal cutter.

SOLUTION.—Applying the rule just given, we have

$$\frac{2.125}{6} = .354 \text{ in., nearly.} \quad \text{Ans.}$$

21. Setting Cutter for Depth.—The cutter may be set to the correct depth by observing the indication of the

graduated dials on the feed-screws. If the gear blank has been turned to the correct size, the cutter is first set to touch the blank; it is then run clear of the blank and the axes of the cutter and blank are brought together an amount equal to the calculated depth of cut. When the gear blank is under size, one-half of the difference between the true diameter and the actual diameter should be subtracted from the calculated depth of cut; the remainder will be the depth to which the cutter is to be set. If the gear blank is over size, it should be turned down.

22. Gear-Tooth-Depth Gauge.—When the blank has been turned to the *correct size*, a **gear-tooth-depth gauge** may be used for marking the correct depth of cut on the blank. Such a gauge is shown in Fig. 1. It has at one end a rectangular slot, the width of which is made equal to the depth of cut for the diametral pitch the gauge is intended for. The point *a* is hardened and is used for scribing a line representing the correct depth of tooth on the blank, by applying the gauge as shown in the illustration and observing the precaution of holding it radially during the scribing. The cutter is then sunk into the blank to the depth indicated by the scribed line.

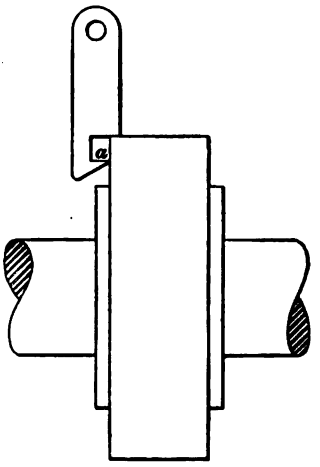


FIG. 1.

GANG CUTTERS.

23. Two or more specially shaped cutters may be placed alongside each other at a distance equal to the pitch, and may be used for cutting the teeth in the same manner as

ordinary single cutters. When several cutters are thus placed, they are called **gang cutters.** They may be divided into two classes, which are: (*a*) Gang cutters that finish teeth to an approximate shape; (*b*) gang cutters that finish teeth to exact shape.

24. The **Clough duplex cutter** belongs to the first class, since one gang of two cutters made as shown in Fig. 2 (*a*) is used for all gears of the same pitch. For gears of more than 30 teeth, the teeth are finished entirely by the inside faces of the cutters, as shown in Fig. 2 (*b*) at *a*; gears having a smaller number of teeth have the flanks of the teeth finished by the outside faces of the cutters, and the faces of

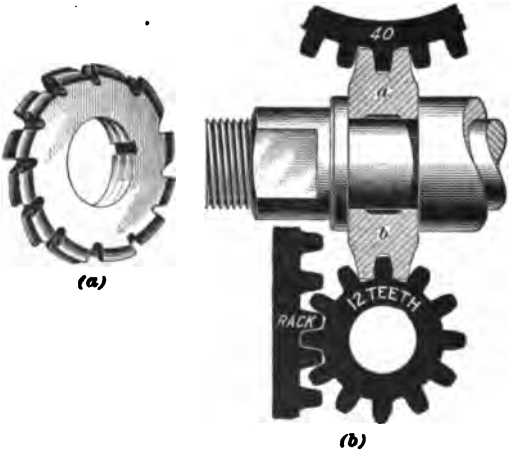


FIG. 2.

the teeth by the inside faces of the cutters, as shown at *b* in the same figure. Gears cut with these cutters will have approximately involute teeth, and different gears cut by the same cutter will run together fairly well. Their motion obviously cannot be as exact as that of wheels cut by a correct single cutter. These duplex cutters are laid out in such a manner that the wheels cut by them will mesh and run with gears cut with regular involute standard cutters.

25. The **Gould & Eberhardt gang cutter** is an example of a cutter belonging to the second class. If the teeth of a gear-wheel be examined, it will be found that usually several of them can be cut at once if the cutter is shaped to conform to the tooth outlines. Thus, in Fig. 3, the cutter *a* conforms to the space *a'*; the cutter *b* conforms to the space *b'*, and as its central plane perpendicular to its axis of rotation passes through the axis of the gear, it is a standard cutter. Finally, the cutter *c* conforms to the space *c'*. By employing three gang cutters thus formed, three teeth can be cut at a time, and, hence, the indexing would be done for three teeth instead of one. In consequence of this, a gear can be cut in less time than is required for cutting it with a single cutter, but owing to the increased heating it cannot be cut in one-third of the time. Since such gang cutters can have the correct shape for only one size of a gear, it follows that a separate gang is required for each size.



FIG. 3.

The Gould & Eberhardt gang cutter is intended primarily for manufacturing—that is, making a large number of equal gears—and in its special field is obviously far ahead of the ordinary single cutter. The large number of gangs required to cover the whole range of gears of each pitch makes it rather unsuitable for jobbing work.

MACHINERY AND ATTACHMENTS.

26. In the formed-cutter process, where a milling cutter is used, the gear may be cut either in a plain milling machine fitted with a suitable indexing attachment, or in a universal milling machine, or in a regular gear-cutting engine.

27. Gear-Cutting Attachment.—The simplest form of gear-cutting attachment does not differ in principle from that of the plain index centers, except that the index plate has only one row of holes and thus a rather limited range of usefulness. Other attachments have a large index plate and a number of different rows of holes so as to extend their range of usefulness. Sometimes a still more elaborate device, like that shown in Fig. 4, is employed. In this the gear blank is mounted on a mandrel and placed between the centers *a* and *b*, or it may be mounted upon an arbor placed in the spindle in place of the center *a*. Inside of the guard *c* there is a worm-wheel which is operated by a worm on the shaft *f*, and the indexing is done by means of an index plate *d*. The device is

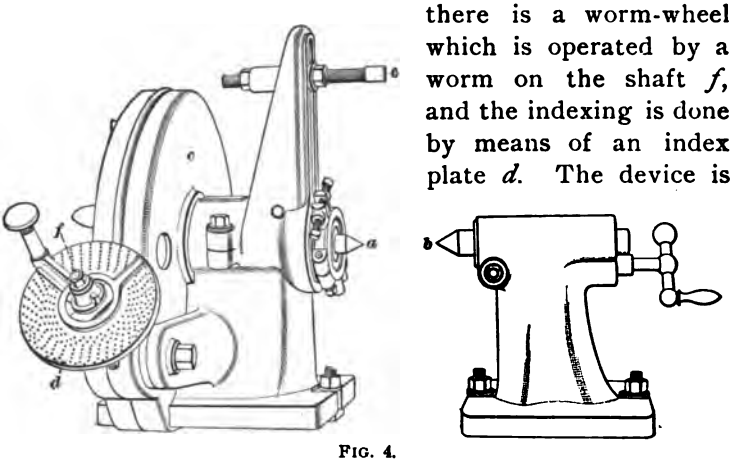


FIG. 4.

so arranged that the worm upon the shaft can be disengaged from the worm-wheel in the case *c*, the worm-wheel rotated by hand, and a plain index pin used in the holes in the back of the plate. The attachment shown can ordinarily be used only for spur gears and sprocket wheels; when fitted to a universal milling machine, it can also be used for gashing worm-wheels.

28. When a universal milling machine is available, spur gears, worm-gears, sprocket wheels, screw gears, and bevel gears can be cut; but bevel gears can be cut only approximately correct.

29. Gear-Cutting Engine.—A regular spur gear-cutting engine is only a special form of a milling machine,

and differs from it chiefly in that, as a general rule, the indexing and also the running back of the cutter is done automatically.

Fig. 5 shows one form of an automatic spur gear-cutting engine built by Gould & Eberhardt, Newark, New Jersey. The gear blank is fastened in some suitable manner to the spindle *a*; generally, an arbor is used, which, in the design shown, is supported at its outer end by the adjustable

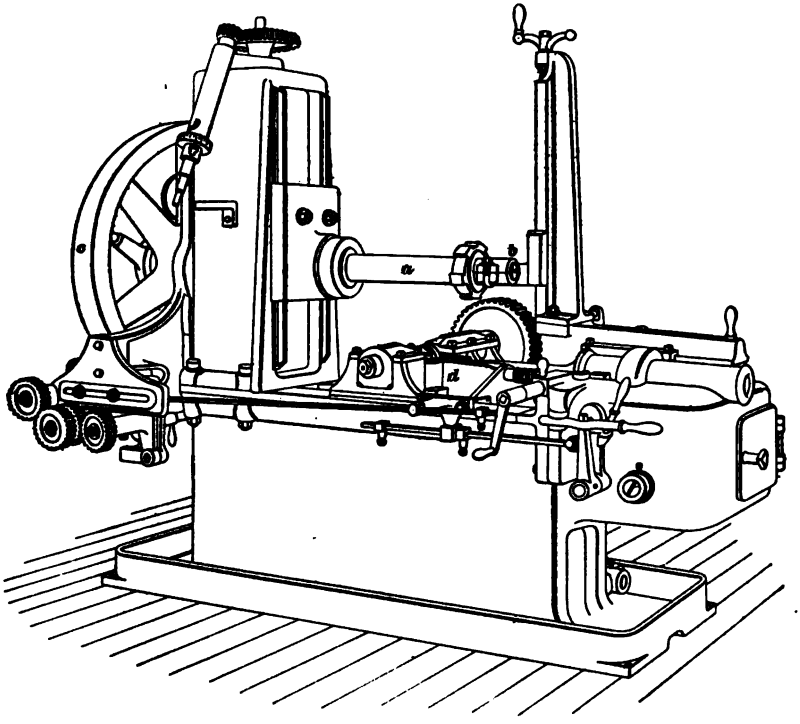


FIG. 5.

outboard bearing *b*. Upon the spindle is fastened a worm-wheel that is enclosed in a guard *c* in order to protect it; a worm meshes with the worm-wheel and is in turn operated by change gears that revolve it a definite part of a revolution each time the cutter is clear of the gear blank and before it begins to cut. The cutter is carried in a

slide *d* that is moved parallel to the axis of the spindle *a*, and is fed automatically to the work and returned. The cutter is adjusted for depth by lowering the gear blank. A limited side adjustment is usually provided for the cutter to allow cutters of different thicknesses to be set central.

30. Automatic gear-cutting engines are often arranged so that they can be used for cutting approximately correct bevel gears. The slide that carries the cutter is then arranged in such a manner that it can be set at the required angle to the axis of the spindle.

31. Change Gearing.—The gearing that revolves the shaft carrying the worm is, as a general rule, actuated by a so-called **stop-shaft,** which is provided with a suitable clutching mechanism operated by the cutter slide. This clutching mechanism is so arranged that it allows the stop-shaft to make exactly one revolution whenever the returning cutter slide unlocks it. The change gears that will produce a certain number of divisions are selected in accordance with the ratio $\frac{\text{teeth in worm-wheel}}{\text{teeth to be cut}}$. In case of simple gearing, this is the simple ratio that gears are to be selected for; in case of compound gearing, it is the compound ratio, which is resolved into factors. The gears are selected in the same manner as is done in gearing a lathe for thread cutting or a milling machine for the cutting of helixes.

In adjusting the gear-cutting engine, the tripping arrangement for the stop-shaft clutching mechanism must be set so that it will act only after the cutter on its return stroke is entirely clear of the gear.

CUTTING BEVEL GEARS WITH FORMED CUTTERS.

32. Selecting the Cutter.—While bevel gears cut with a cutter of fixed curve can be only approximately correct, the comparative cheapness of this method has led to its being largely used. The ordinary cutters made for spur

wheels should never be used for this purpose, as they will cut the teeth of the bevel gear entirely too thin at the small end. Special miter-gear and bevel-gear cutters are made for this purpose; these cutters are of the involute form, but thinner than the standard cutters. They are numbered from 1 to 8, and cover the same range as the standard involute cutters. A bevel-gear cutter cannot be selected in the same manner as the ordinary spur-gear cutter, that is, directly in accordance with the number of teeth of the bevel gear. It is to be selected, instead, for a number of teeth that is calculated by one of the rules given below, the first of which is as follows:

Rule.—*To find the number of teeth a bevel-gear cutter is to be selected for, divide the number of teeth of the bevel gear by the natural cosine of the center angle a d e, Fig. 6.*

EXAMPLE. —The center angle of a bevel gear having 24 teeth is 53° 15′. What number of teeth should the cutter be selected for?

SOLUTION.—The cosine of 53° 15′ is .59832. Applying the rule, we get $\frac{24}{.59832} = 40$ teeth. Referring to the Table of Standard Cutters, we find that for gears having between 35 and 54 teeth, a No. 3 cutter is to be used. Hence, use a No. 3 bevel-gear cutter. Ans.

33. When a drawing of the bevel gear is available, use the following rule:

Rule.—*Measure the slant height of the back cone, as a b in Fig. 6; double it and multiply by the diametral pitch. The product will be the number of teeth the cutter is to be selected for.*

EXAMPLE.—The slant height of the back cone being 5 inches, and the diametral pitch being 4, what number of bevel-gear cutter is to be used?

SOLUTION.—Applying the rule just given, we get $5 \times 2 \times 4 = 40$ teeth. Referring to the Table of Standard Cutters, it is seen that a No. 3 bevel-gear cutter is to be used. Ans.

34. Setting the Machine.—The cutter having been selected, place it on its arbor; put the gear blank into the

machine, and set the latter to the cutting angle. Now, set the cutter central in respect to the gear blank; then set it to the correct depth of cut, measuring at the large end of the blank, and cut two adjacent tooth spaces, as *b* and *c* in Fig. 7, which leaves the tooth *a* rather too thick. Set the cutter off center an amount equal to about $\frac{1}{10}$ the thickness of the tooth *a* at the large end. Now, revolve the gear blank toward the cutter until the latter will enter one of the central cuts *b* or *c* at the small end of the gear and cut the one side of the tooth *a*. Next, set the cutter off center to the other side of the center by the same amount and roll the blank toward the cutter again until it enters the other central slot at the small end. Take the cut, and measure the thickness of the tooth *a* at the pitch line at the large end. If its thickness is more than the quotient

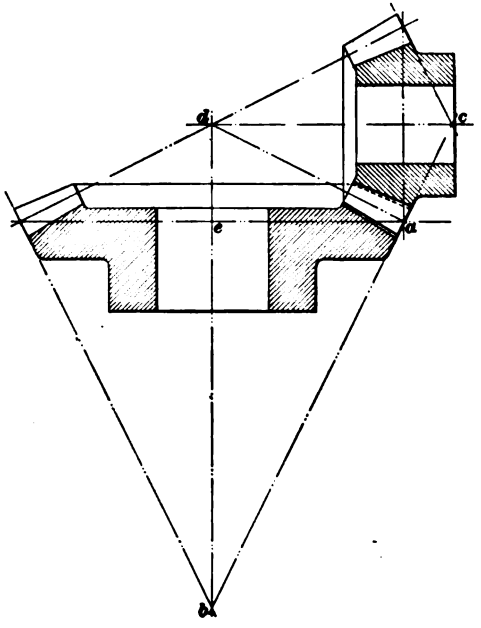


FIG. 6.

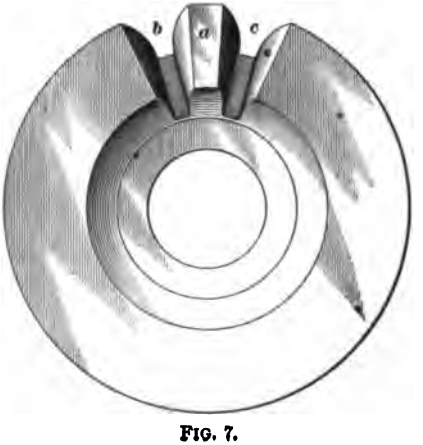


FIG. 7.

obtained by dividing the circumference of the pitch circle by twice the number of teeth, it shows that the cutter must be set farther off center. This having been done, the blank is rolled toward the cutter and both sides of the tooth *a* are cut again, and the cycle of operations is repeated until the tooth is of the correct thickness at the large end. The gear blank can now be cut, first setting the cutter off center one way the amount determined by trial and cutting all around the gear, and then setting it off center the other way and going around once more.

35. The method given in Arts. **32, 33,** and **34** will answer fairly well for teeth that are shorter than $\frac{1}{3}$ the slant height of the pitch cone; it will leave the teeth correct at the large end, but not rounding enough at the small end. The teeth must consequently be dressed with a file.

36. Gear-Tooth Caliper.—A good form of a caliper for measuring the thickness of the gear-teeth is shown in Fig. 8. The vertical slide *a* is first set until the reading of

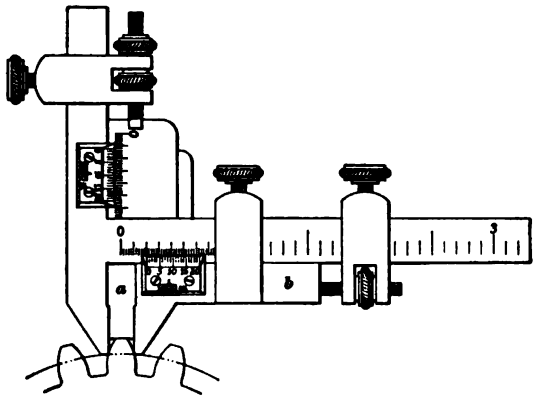


FIG. 8.

its vernier is equal to the calculated addendum of the tooth; the caliper is then applied to the gear with the slide *a* resting on top of a gear-tooth, as shown, and the horizontal jaw *b* is

brought against the tooth. The thickness of the tooth is read on the horizontal vernier.

37. General Instructions.—When miter gears are cut, both gears of a pair are cut with the same cutter; when bevel gears are cut, the proper number of the cutter should be computed for each by the rules previously given. If the cutting is done in a machine where the angle between the axis of the index-head spindle and the axis of the cutter spindle can be changed, the angle should be made 90° before beginning to set the machine. This gear-tooth caliper does not give good results when applied to the teeth of small pinions unless care is taken to see that the points of the jaws are in contact with the pitch points of the teeth. This may necessitate the setting of the vertical scale to a greater distance than the addendum.

RACK CUTTING.

38. A rack may be cut either with a planing tool or a milling cutter shaped to conform to the rack teeth. The pitch of the rack is equal to the pitch of the spur gear meshing with it, and since cut spur gears are made almost entirely to the diametral-pitch system, the circular pitch must usually be computed from it to obtain the spacing.

39. Short racks can readily be cut in the horizontal milling machine, using the cross-feed screw to obtain the spacing and the regular longitudinal-feed screw for feeding. The rack blank may either be clamped to the table or be held in the vise or in a special fixture.

40. Racks that are too long to be cut in this manner can be cut by means of a special rack-cutting attachment, one form of which is shown in Fig. 9. The cutter *a* is placed at right angles to its normal position; this allows the feed-screw *b* to be used for spacing the teeth and the cross-feed screw for feeding. A graduated dial *c* reading to .001 inch is placed on the feed-screw, and the correct

spacing is obtained by means of it. The rack may be placed in a fixture *d* made as shown, which will take several racks at one time.

41. When racks are cut in the milling machine, it is strongly recommended that the gibs of the part that is moved in order to obtain the spacing be set up more firmly than usual in order to create enough friction to prevent any shifting, which is liable to occur by reason of the backlash of the feed-screw.

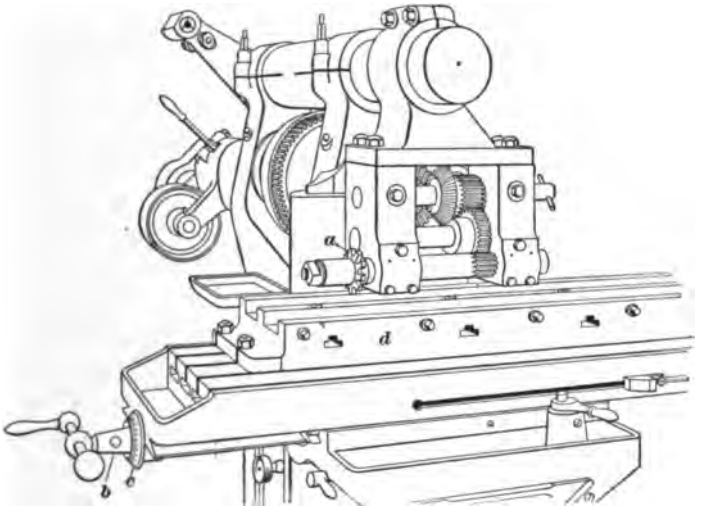


FIG. 9.

Racks are often cut in milling machines of the planer type; in that case, the spacing is obtained by means of the feed-screw in the cross-rail. The head should then have its gibs set up rather firmly. The rack is placed square across the platen.

A planing tool formed to the correct shape may be used in a planer, shaper, or slotter, obtaining the spacing by means of whatever feed-screw can be used for the purpose.

TEMPLET-PLANING PROCESS.

42. The Machine.—The principle of operation of a templet-planing machine intended for planing the teeth of bevel gears is shown in diagrammatic form in Fig. 10. The gear blank *a* is attached to the index spindle *b*, which carries an indexing wheel *c* at its other end. An arm *d* supports a longitudinally movable slide *e* which carries the pointed cutting tool *f*. The arm *d* is mounted on a universal joint in such a manner that its center of rotation *g* coincides with the axis of rotation of the gear blank. The

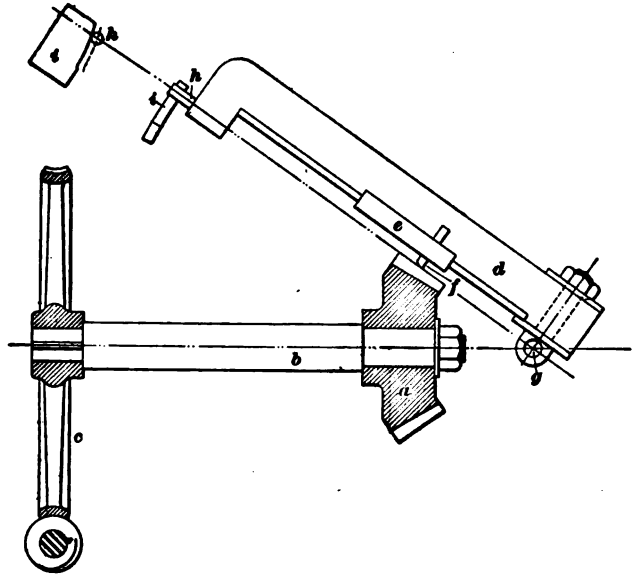


FIG. 10.

cutting tool is adjusted in the slide *e* in such a manner that the line of motion of its cutting point passes exactly through the center of rotation of the arm. A pin *h* is fastened to the free end of the arm, and is in contact with a templet *i*, which is shaped to conform to a correct tooth curve for the number of teeth contained in the bevel gear.

The arm *d* remains stationary while the cutting tool is traversed through the gear blank. One side of a tooth is finished at a time by successive cuts converging toward the apex of the pitch cone, which point, by reason of the construction of the machine, is also the center of rotation *g* of the arm. After the tool *f* has cleared the blank on its return stroke, the arm is moved slightly along the templet *i*, keeping the pin *h* in contact with the templet; the position of the arm and, hence, the formation of the tooth curves, is thus determined by the templet. The form of the templet is reproduced on a smaller scale by the planing tool on the tooth operated on, and any errors existing in the templet are reduced.

43. It is obvious that a different templet will be required for each number of teeth, at least theoretically. Owing to the small divergence in the shape of the tooth curves, one templet can be made to serve for several gears, however, just as is done with formed gear-cutters. One templet will answer for all pitches within the range of the machine; different sizes of bevel gears are cut by varying the distance from the gear to the center of rotation of the arm *d*. In an actual machine, the templet is movably mounted on a quadrant having its center of curvature at *g*; this adapts the machine for different gears, since it allows the angle between the axis of the spindle and the line of motion of the tool to be changed to suit the number of teeth of the gear.

44. Templet-Grinding Process.—A modification of the templet-planing process has recently been perfected by the Leland & Faulconer Company, Detroit, Michigan, who have substituted a corundum wheel for the planing tool and thus are enabled to finish the teeth of hardened-steel bevel gears to a correct shape. The fundamental principle underlying this **templet-grinding** process does not differ in any essential particular from that explained in connection with Fig. 10.

GENERATION SYSTEM.

CONJUGATE-TOOTH METHOD.

MOLDING PROCESS.

45. The different processes employed in the conjugate-tooth method of generating gear-teeth are all based on the so-called **molding process,** which has not been put into practical use, however, at least not to any extent. This process may be explained as follows: Let a correctly formed rack made of some hard material, as steel, be passed over a gear blank made of a plastic material, as beeswax, while the blank is given a positive rotation that imparts to it at the pitch circle a velocity equal to that of the rack. Then, the pitch line of the rack and the pitch circle of the blank being tangent, the teeth of the rack will mold teeth in the blank that are conjugate to its own.

MOLDING-PLANING PROCESS.

46. Principle of Operation.—Since the materials of which gear-wheels are constructed are not plastic, the molding process cannot be employed very readily, but the same effect can be produced by transforming the generating rack into a cutting tool that reciprocates across the blank in the direction of the axis of the latter. The cutting tool does not advance during its *cutting stroke* in a line tangent to the pitch circle of the blank and at right angles to the axis of the latter; but, after the tool has cleared the blank on its return stroke, the tool and the gear blank are given a slight motion equivalent to that of a meshing rack and pinion and the tool is reciprocated through the blank again. This cycle of operations is repeated until the gear blank has been transformed into a gear. The molding process thus becomes the

molding-planing process; in execution, however, this process is modified for practical reasons, the chief of which are the great length of rack required and the difficulty of making it.

47. Fellows Gear-Shaper.—In the **Fellows gear-shaper,** in which machine the molding-planing process is employed, the cutter *a*, Fig. 11, is made in the form of a gear. The process by which the cutter is generated is equivalent to its generation by an involute rack, and it is

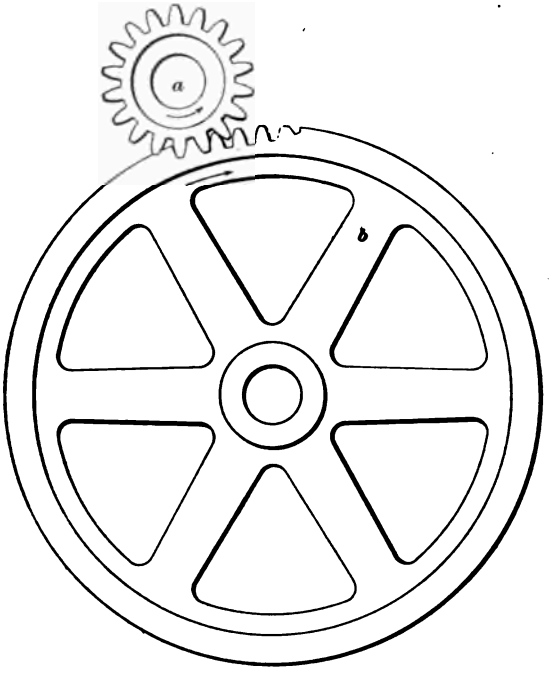


FIG. 11.

given teeth conjugate to those of the generating rack. In consequence of the method by which the cutter is formed, the teeth of all gears cut by it are conjugate to the rack and hence to one another; that is, the different gears will run together correctly.

In use, the cutter *a* is drawn axially across the face of the blank *b* and cuts grooves corresponding to the shape of its teeth. In beginning to cut a gear, the blank and cutter do not revolve, but the center-to-center distance between the cutter and the gear blank is shortened after each return stroke of the cutter until the correct depth of cut is reached. The cutter and the gear blank are then rotated a little by positive means after each return stroke in the direction shown by the arrows; their relative rotations are exactly the same as if two gears equal in size to the cutter and gear to be cut were rolling together. Conjugate teeth are thus generated, and one cutter will cut all gears from a pinion to a rack.

48. The machine used is shown in Fig. 12. The cutter *a* is carried on the end of a ram that is free to slide in a vertical direction and can be rotated about the cutter axis. This ram is carried in a head *b*, which is gibbed to ways formed on the frame and is movable horizontally to suit different diameters of gears and different depths of cut. The gear blanks *c*, *c* are mounted on a vertical spindle parallel to the line of motion of the ram. The lower end of the spindle that receives the blank carries a worm-wheel enclosed in the guard *d*; a worm meshes with this wheel and in turn is connected to change gearing that connects the ram and the spindle by a suitable mechanism and forces them to rotate together. Different velocity ratios are obtained by changing the change gears. The ram, sliding axially in its bearings, is reciprocated across the face of the blank. The gear blank is supported against the cut by an adjustable jack *e*. Ordinarily, the cut taken is a draw cut, the cutter being drawn across the face of the blank; the machine can readily be used, however, for pushing the cutter across the blank. The stroke of the ram is adjustable for length and position.

49. Internal gears can be cut with the same ease as spur gears by means of this machine, and the cutter will automatically produce teeth conjugate to itself and to any

spur gear cut by the same cutter. Sprocket wheels can also be cut by using a suitably formed cutter.

50. The cutter is a spur gear having excessive addendum on one side and excessive dedendum on the other, causing it to look like a bevel gear. As is well known, any planing tool must have clearance in order to cut; this cutter is no exception to the general rule, and is given clearance

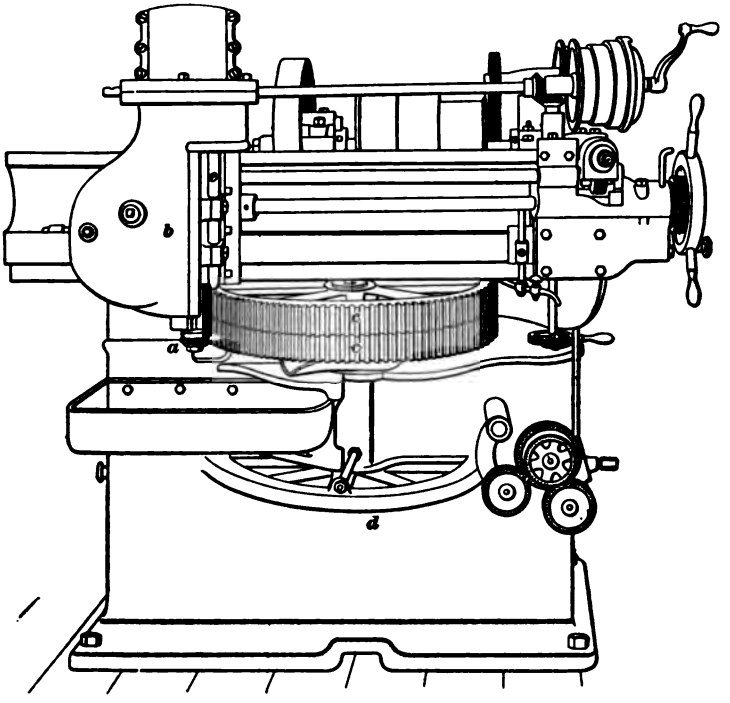


FIG. 12.

by making it like a bevel gear. It is sharpened by grinding its top face in a special grinding machine; while it is true that this grinding will change the pitch of the cutter, the fact remains that, owing to the small inclination of the teeth, the reduction in pitch will be so extremely small as to be negligible for all practical purposes.

SINGLE-TOOTH MOLDING-PLANING PROCESS.

51. Development of the Process. — As previously explained, in the molding process the teeth of a gear are formed by running a rack over the gear blank, as is shown in Fig. 13 (*a*). It is readily seen that this operation may be

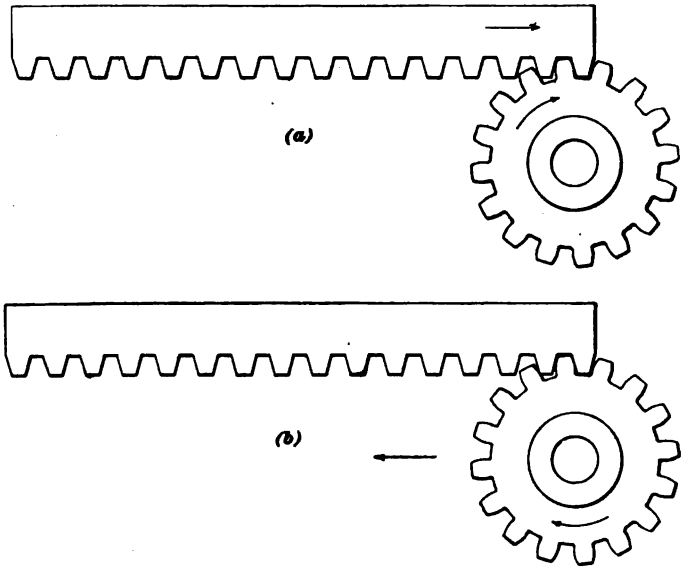


FIG. 13.

reversed; that is, the rack may remain stationary and the gear blank may be rolled along it in order that teeth conjugate to those of the rack may be generated. This is shown in Fig. 13 (*b*).

52. The rack may be replaced by a single stationary tooth, as illustrated in Fig. 14; then, if the gear blank is rolled past this tooth with a motion equivalent to that of a pinion rolling in a rack, the single tooth will mold opposite sides of two future adjacent teeth to a form conjugate to its own. Fig. 14 (*a*) shows the position of the molding tooth when it first engages the gear blank, which is rolled in the direction of the arrow x and, consequently, advances along the straight line $a\,b$ in the direction of the arrow y. In

Fig. 14 (*b*), the blank has been rolled into the position shown, its original position being given by the dotted circle *c*. The center *d* of the gear blank is here perpendicularly below the molding tooth, and the face of one tooth and the flank of another have been fully formed. In Fig. 14 (*c*), the blank has been rolled forwards until the

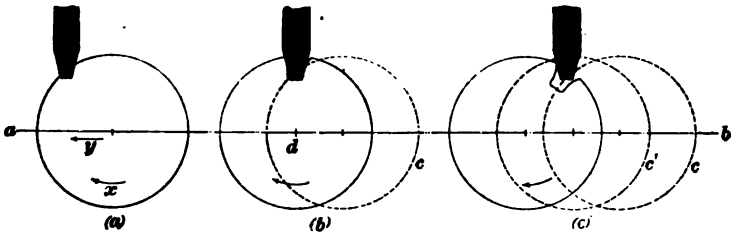


FIG. 14.

molding tooth is about to leave the blank, and the opposite faces of two future adjacent teeth have been fully formed; that is, one space has been molded. In order to show the rotation and advance of the blank more clearly, several of its different positions are given; the dotted circle *c* represents the position occupied in Fig. 14 (*a*), and the dotted circle *c'* gives the position shown in Fig. 14 (*b*).

53. Since a single-tooth molding tool can finish only one space at a time, it follows that after each passage of the tool, the blank must be rotated by a suitable indexing mechanism through an angle corresponding to one tooth.

54. The single molding tooth may be made in the form of a planer tool and may then be given a reciprocating motion across the face of the blank; after it has cleared the blank on the return stroke, the blank may be revolved and advanced forwards a little and the tool be reciprocated through it again. This cycle of operations being repeated until the tool does not engage the blank any more, the opposite sides of two future adjacent teeth are thus formed by successive cuts to be conjugate to the gear-tooth represented by the planing tool.

55. The single-tooth molding-planing process just explained forms the basis of a mechanical method of correctly generating the teeth of bevel gears that are conjugate to those of a **circular rack,** which is often called a **crown gear.** The principle underlying this method may be explained as follows: When a spur gear rolls in a rack, its action is equivalent to that of the pitch cylinder rolling without slipping on the pitch plane of a rack, and the path

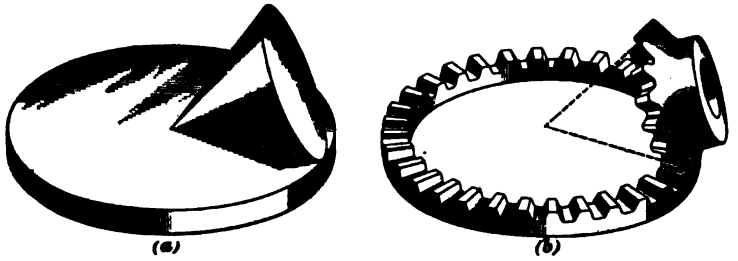


FIG. 15.

of the pitch cylinder will be represented by a straight line. In a bevel gear we have a *pitch cone* instead of the *pitch cylinder* of the spur gear; such a cone in rolling without slipping on a plane surface will follow a circular path, and the apex of the cone will coincide with the center of the circle representing the path, as is shown in Fig. 15 (*a*). From this it follows that the rack for a bevel gear must be circular, as is shown in Fig. 15 (*b*).

56. Obviously, a circular rack may be used for molding the teeth of a bevel gear in the same manner in which a straight rack may be employed for generating the teeth of a spur gear, rolling the bevel-gear blank along the circular rack just as the pitch cone in Fig. 15 (*a*) would roll without slipping on the plane surface representing the pitch plane of the rack. As was explained in connection with spur gears, the rack may be replaced by a single tooth; when transforming the molding tooth into a planing tool, however, we are immediately confronted with the fact that the pitch of the tooth, and, hence, the width of the space

between two teeth of a circular rack, changes throughout the length of the tooth. This fact precludes the possibility of planing opposite sides of adjacent teeth in one cut.

57. In a circular rack, neither the involute nor the epicycloidal form of tooth can be planed with a *formed* planing tool, for in such a rack these tooth curves, although remaining symmetrical, change in extent throughout the length of the tooth. This method was employed in the Bilgram bevel-gear cutting machine before it was discovered by Mr. Geo. B. Grant that the teeth were not true involute teeth. A circular rack having its teeth planed one side at a time with a formed tool given the shape of an involute straight-rack tooth, would form the basis of a new system of bevel-gear teeth whose sides in the circular rack are plane surfaces, and to which Mr. Grant has given the name of **octoidal teeth.**

58. The octoidal bevel-gear tooth (a circular rack is here considered as a special form of a bevel gear) being formed by a tool having the shape of an involute straight-rack tooth, it naturally has the same general form as the true involute bevel-gear tooth, and, hence, has been, and is yet, confounded with it by many writers on the subject of gear-cutting.

59. Since a circular rack may generate teeth conjugate to its own by molding, it is a logical conclusion that the molding process may be replaced by the molding-planing process, as is done in the case of spur gears generated by a straight rack. Instead of planing parallel to the axis of a pitch cylinder, however, the planing of a bevel gear must be done toward the apex of its pitch cone, and the planing tool must move parallel to the bottom of the teeth, as is done in planing the crown gear.

60. The planing tool is, in practice, made slightly narrower than the width of the space between teeth at their smaller end; it is then reciprocated through the gear blank in the same direction that the sides of the teeth of a circular rack occupy; that is, radially toward the center of the rack

and, hence, toward the apex of the pitch cone. After each cut, the gear blank is given a motion equivalent to that of its pitch cone rolling on the pitch plane of a circular rack; by successive rollings of the blank and passages of the cutting tool through it, one side of one tooth is made conjugate to the side of the tooth of a circular octoidal rack. By suitable indexing and a repetition of the forming operation for the opposite side of each tooth, a correct octoidal bevel gear is cut that has teeth conjugate to those of the corresponding circular rack; consequently, both bevel gears of a pair thus cut have teeth that are conjugate to one another, and, hence, will run together correctly.

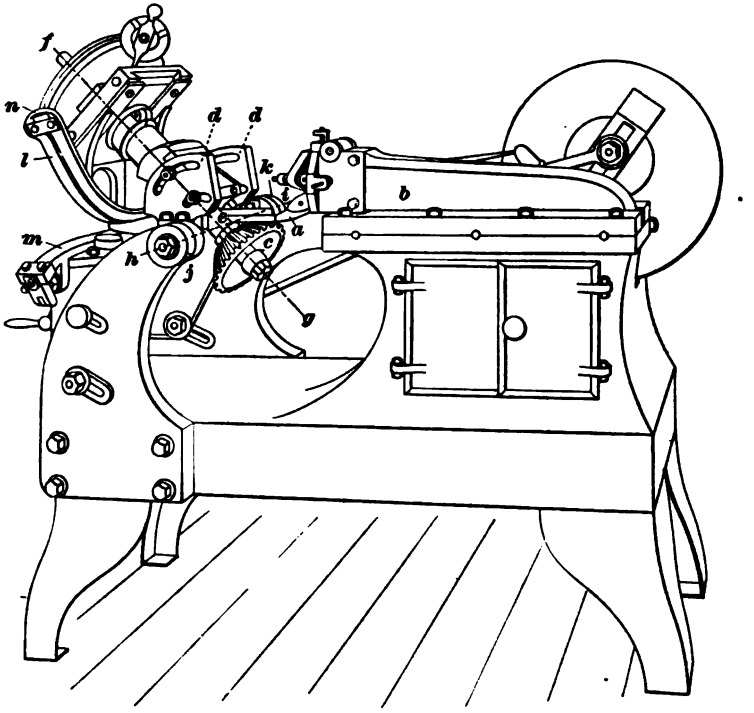


FIG. 16.

61. Bilgram Bevel-Gear Cutter.—The method of generating conjugate bevel-gear teeth that has been just

explained is employed in the **Bilgram bevel-gear-cutting machine** shown in perspective in Fig. 16. In this machine, the planing tool *a*, which is formed to conform to the sides of the teeth of a circular involute rack, is held in the tool post of a crank-driven ram *b* that reciprocates in suitable guides formed in the frame of the machine. The tool post is set into a clapper similar to that of a planer head, in order to allow the tool to swing away from the work on the return stroke.

62. The gear blank receives a rolling motion from a very interesting piece of mechanism. The gear blank *c* is mounted upon a spindle *e*. The axis *fg* of the spindle *e* intersects an axis *hi* passing through the bearings *j* and *k*. The piece *n* is made in the form of a portion of a conical surface, the apex of the cone being at the intersection of the axes *fg* and *hi*. About this conical surface two bands *l* and *m* are arranged so that as the portion of the machine carrying the axis *fg* is swung backwards and forwards the bands *l* and *m* will cause the spindle *e* to rotate about the point where the axes *fg* and *hi* intersect. By properly adjusting the gear *c*, so that the tool *a* travels in the direction of the bottom of the gear teeth, the machine will be so set that the rotating of the conical surface *n* will cause the gear *c* to rotate as though it were in contact with a gear tooth represented by the tool *a*.

63. The machine is provided with such adjustments that the gear blank *c* can always be brought into the proper relation to the cutting tool *a*, without the necessity of having the piece *n* constructed as a cone having the same central angle, the only requirement being that the conical piece *n* shall give the axis *fg* the proper rotation about the intersection of the two axes *fg* and *hi*. The effect of the motion is the same as if the bevel gear *c* were rolling upon a circular rack, one tooth of which is represented by the cutting tool *a*. A suitable indexing mechanism spaces the teeth correctly and an automatic feed mechanism rolls the blank slightly after each return stroke of the forming tool *a*.

MOLDING-MILLING PROCESS.

64. Principle of Operation.—The principle of operation underlying the molding-milling process is illustrated by the aid of Fig. 17. Equal cutters *a*, *a*, in series, the profile of each of which is the same as that of a rack tooth, are placed alongside one another on a mandrel and at a distance from one another equal to the circular pitch, so that a longitudinal section taken through all the cutters shall have the outline of the teeth of a rack. The number of cutters is made equal to the number of teeth the proposed gear is to have. The gear blank *b* is mounted on an arbor at right angles to the axis of rotation of the cutters, and the gear blank and cutter arbor are so connected by gearing that when the blank rotates in the direction of the arrow *x*, the cutter arbor will

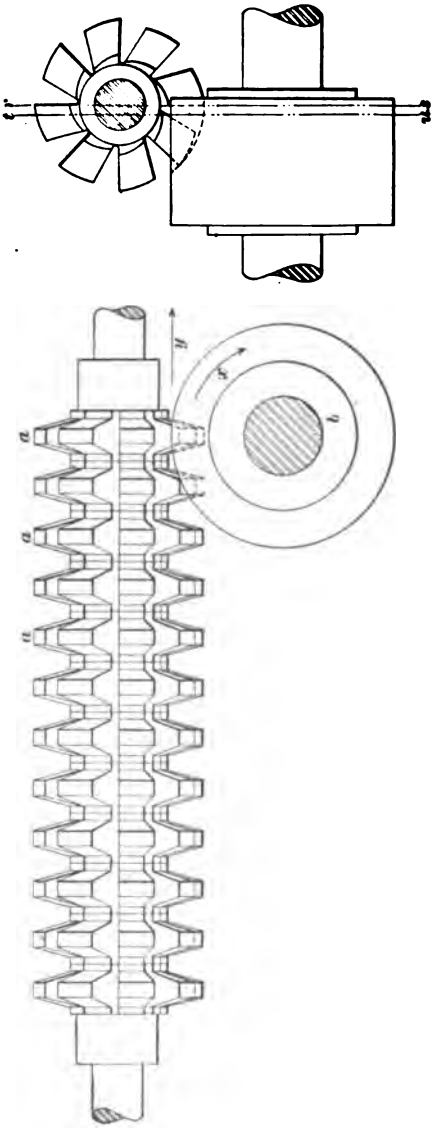


FIG. 17.

advance in the direction of the arrow y at exactly the same velocity; that is, the cutter arbor and gear blank will move in relation to each other exactly as if they were a rack and pinion in mesh.

65. Let the gear blank and cutter be brought together as shown in the end view, the cutter revolving about its axis and cutting into the blank. Then, if the blank is rotated at the same time that the cutter is moved in the direction of its axis, the cutter teeth will cut out grooves in such a manner that their profile in the plane $r\ s$ will be that of teeth conjugate to those of the rack represented by a longitudinal section of the cutter. When the blank has revolved one turn, let the cutter and the blank be separated; return the cutter to its original position; bring the blank and cutter together again, and feed the cutter over the blank until the cutting is done in a plane $t\ u$ slightly in advance of $r\ s$. After this cut has been taken all around the blank, let the cycle of operations be repeated again and again until the cutter has been clear across the face of the gear blank. The teeth thus produced will be conjugate to those of the rack whose profile is given by a longitudinal section of the cutter.

66. Swasey Cutter.—The practical objections to the method of procedure just explained are the great number of cutters required and the deflection of the arbor on which they are carried. These objections have been overcome in an ingenious manner by Mr. Ambrose Swasey, and the process has thus been made mechanically practical.

An end view and partial sectional elevation of the **Swasey cutter** is shown in Fig. 18. Each cutter is seen to be divided into two parts, and the cutters are all connected together into two independent sections, each of which is mounted on two cylindrical rods passing through the holes shown. The four rods pass through cylindrical sleeves at each side of the cutters; the holes in the sleeves through which the rods pass are placed in such a relation to the axis of the sleeves that upon revolving them the cutters will run true. Each section of cutters is moved in the direction of

the axis by a cam at the same time that they revolve; as soon as one section during its revolution has cleared the gear blank, the cam throws it back to its original position, and just before commencing to cut it begins to slide forwards

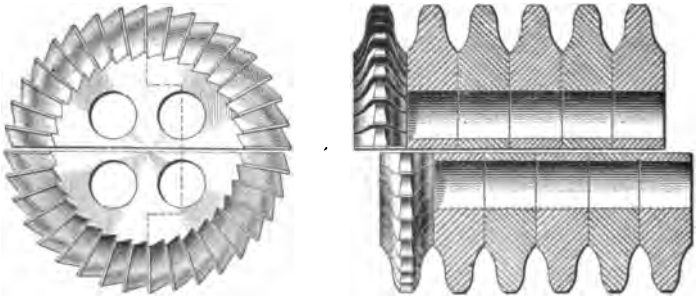


FIG. 18.

again at a velocity equal to that of a point on the pitch circle of the gear blank. It will be understood that while one section of the cutters is engaged with the blank, the section clear of the blank is being returned to its original position.

67. The motion of each section of the cutter during one of its revolutions can be easier understood by simply considering the motion of a point on the periphery of one cutter

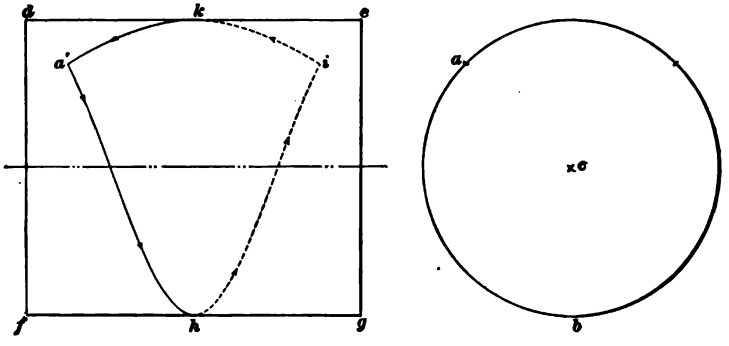


FIG. 19.

in one section. For instance, consider the point *a* in Fig. 19, where the circle *b* represents the periphery of the cutter. Then, as this point remains at a constant distance from the

axis of rotation represented by the point c, it follows that during any axial movement the point a will follow a path lying on the surface of a cylinder, as $d e g f$. Let the point whose motion we are considering be at a' on the surface of the cylinder. Then, as soon as the gear blank and cutter begin to move in respect to each other, the point a' during the rotation and axial advance of the cutter follows the right-handed helical path $a' h i$ in the direction given by the arrows. When the point a' reaches the position i, the cam constraining the axial motion of the cutter commences to return it to its original position, and the point whose motion we are considering returns along the left-handed helical path $i k a'$ to its starting point a'.

68. By timing the action of the two sections in such a manner that when one is at the limit of its forward travel and about to return, the other section is just beginning to travel forwards, the cutting action of the two sections is made equivalent to that of an infinite number of equal cutters, similar to those shown in Fig. 17, placed alongside each other. After the Swasey cutters have passed once clear around the wheel that is being cut, the cutters are advanced a little in front of the plane in which the cut just finished was taken and the new cut is taken all around the gear blank again. This cycle of operations is repeated automatically until the cutters have been across the whole face of the wheel.

69. The Swasey process of generating gear-teeth involves the use of a special machine. In this machine the cutter and the gear blank are connected together in such a manner that the cutter makes, during each revolution of the gear, a number of revolutions exactly equal to the number of teeth which the gear to be cut is intended to have. While this is unnecessary in the process described in Art. **64**, it is absolutely essential with the modified cutters used, in order that the cams giving the axial motion to the cutter sections shall time the motions correctly.

70. Molding-Milling Bevel Gears. — A molding-milling process for generating octoidal bevel-gear teeth has recently been brought out by Mr. Warren, and a number of special machines for it have been built by The Pratt & Whitney Company, of Hartford, Connecticut. This process is based on the Bilgram bevel-gear planing process; a milling cutter having a section equal to that of an involute straight-rack tooth is substituted for the planing tool, however. The gear blank is given the same rolling motion as is done in the Bilgram machine, and octoidal teeth conjugate to those of a circular rack are formed. In this process, two milling cutters are employed, in order to finish both sides of a tooth at once; their lines of motion converge toward the apex of the pitch cone.

MAKING WORM-WHEELS.

71. In practice worm-wheels are cut either approximately or exactly correct. In the former case, a formed involute spur-gear cutter having a designating mark corresponding to the number of teeth equal to the number of turns of the worm for one revolution of the worm-wheel, is used; in the latter case, a special rotary cutter, called a **hob,** is employed, and generates teeth conjugate to its own.

72. Cutting With a Formed Cutter. — When a formed cutter is used, the teeth are generally cut in a straight path diagonally across the face at an angle corresponding to that of the worm, but otherwise cutting the worm-wheel as if it were a spur gear. In practice, the angle that the teeth make with the axis of the worm-wheel is found by trial; the index head of the universal milling machine is swiveled on its table for this purpose and a few teeth are cut. The worm is then tried in these teeth to see whether its axis is at right angles to that of the worm-wheel; the setting is changed if this is not the case. Owing to the liability of spoiling the gear blank by these trial cuts, it is recommended to use a hardwood blank of the same size to experiment on.

73. Hobbing.—Hobbing will produce the best worm-wheel, and is the process that should always be employed for a wheel subjected to much use. The hob is shown in Fig. 20. It will be noticed that it is nothing but a worm that has been serrated in order to form cutting edges. In order that the thread of the worm may clear the bottom of the corresponding spaces in the worm-wheel, the thread of the hob is made slightly higher than that of the worm.

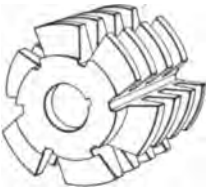


FIG. 20.

74. In hobbing a worm-wheel, the wheel is placed on an arbor between the centers, but is not confined by a dog, so that it is free to rotate about its axis. The hob is placed at right angles to the axis of rotation of the worm-wheel and while revolving is sunk into the face of the worm-wheel to the desired depth. The hob, in continuing to revolve, rotates the worm-wheel and cuts its teeth to a shape conjugate to that of its own.

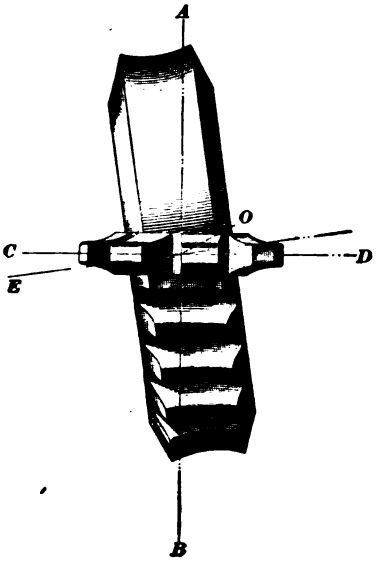


FIG. 21.

75. A worm-wheel that is to be hobbed should always be prepared for hobbing by notching it with an involute cutter slightly narrower than the face of the hob teeth. This process is called **gashing**, and is done in a horizontal machine as follows: The blank is mounted on an arbor and placed between index centers, which are arranged to index for the number of teeth the worm-wheel is to have. The milling-machine table, after being set to zero, is moved

horizontally until the axis $A\,B$ of the cutter is in the central plane of the worm-wheel, as shown in Fig. 21. The table is then swung on the saddle until the angle $B\,O\,E$ corresponds approximately to the angle of the helix of the worm, and the notches are cut, raising the knee by means of the vertical feed. The table is then swung back to zero and the hob is used for finishing the teeth. Since the worm-wheel is driven by the hob, the notches must be deep enough and wide enough to insure good driving when the hob is first applied. If hobbing is attempted without previous gashing, it will often happen that a greater number of teeth than is desired will be obtained.

76. In machines designed especially for cutting worm-gears, the hob and wheel blank are connected together by gearing that drives the wheel blank at the proper speed. Gashing may be omitted in such machines, since the change gears insure a correct spacing of the worm-wheel teeth.

EXAMPLES OF SPECIAL CASES OF CONJUGATE GEARS.

77. Spiral Bevel Gears. — Fig. 22 shows a pair of miter gears with the teeth planed in a spiral, so that one tooth shall always be in deepest contact when the gears work together. These gears work together almost perfectly; in fact, unevenness cannot be detected by observation. The term *herring-bone gears* has been applied to them. Their surfaces are not warped but are truly conical, so that the shafts are in the same plane and at right angles to each other.

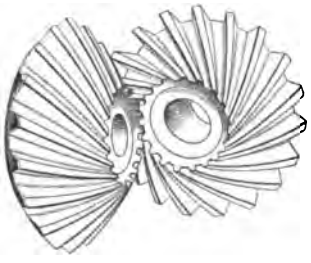


FIG. 22.

78. Special Bevel Gears. — The four bevel gears working together, shown in Fig. 23, are somewhat remarkable, as it was for a long time thought impossible to make such gears so that they would work together properly. The

gear-model here shown was made by Mr. Hugo Bilgram on the machine shown in Fig. 16. The large gear has 36 teeth, the others 12, 18, and 24 teeth. The 36-tooth and 18-tooth gears mesh together correctly, according to the ordinary method of design. In order that the two pitch cones of bevel gears shall roll together without slipping, their vertices must meet in a point.

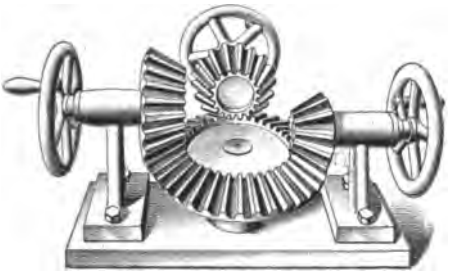


FIG. 23.

The diagram of four pitch cones in Fig. 24 (*a*) shows how the pitch cones of the gears shown in Fig. 23 would lie with respect to one another in ordinary practice. The two cones *a* and *b* would roll together without slipping, but *c* and *d* would not roll on *a* without slipping. In order to make the gears so that they would have a constant velocity ratio, some part of the teeth must have moved as if the pitch cones slipped on each other, but in correctly formed gears the pitch circles must roll together without slipping. The manner in which this is accomplished is illustrated in Fig. 24 (*b*). The gears *a* and *b* will roll together properly as their pitch cones meet at the point of intersection of their axes, but the vertex of the cone *c*, Fig. 24 (*a*), does not come to the same point. New

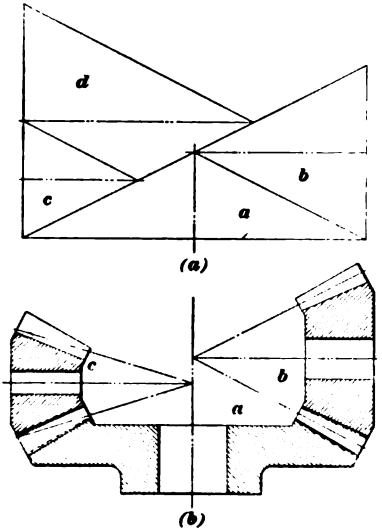


FIG. 24.

pitch cones must therefore be assumed, which changes the relation of the addendum and dedendum of the teeth at different points of their length. There will be the least variation when the middle of the tooth has correct addendum. The large end of the teeth of the gear *c* will have excessive addendum, as shown in Fig. 24 (*b*), and the small end will have excessive dedendum, but diminished addendum. If the gear *c* had been larger than the gear *a*, the conditions would have been reversed. It would seem difficult to produce such teeth so that the gears would run together smoothly, but it has been done. The machine shown in Fig. 16 was used with slight variations, most of which were merely adjustments. The gears run very smoothly, indeed. These gears have proved very useful in certain special machines. The limit of variation from the standard bevel gears is reached when the flanks of the teeth become too much undercut.

GRINDING.

(PART 1.)

INTRODUCTION.

1. Definition of Grinding.—Generally, the term "grinding" is used to designate the operation of reducing a substance to a powder by friction or trituration. It is also used to designate the act of sharpening tools. In the present section, it will be understood to mean the polishing, finishing, or sharpening of tools or metal parts (mostly hardened steel) by means of revolving wheels composed of or covered with angular grains of some abrading material that is harder than the substance to be cut.

The grinding process is characterized by the fact that the material removed is all reduced to a fine powder, and on this account the amount of power necessary to remove a given weight of material by grinding is greater than would be the case with a machine tool that produced larger chips.

2. Grinding Materials.—All grinding is done by the angular grains of some hard substance that are held in place while doing the grinding by being bedded in a softer substance, or that are so cemented or united together as to form a wheel or a rectangular mass.

Most grinding materials are used in the form of wheels, and may be divided into the two classes, *grindstones* and *grinding wheels*, the latter including all *emery*, *corundum*, and *carborundum* wheels. There is another small class that would then come under the heading of *oilstones*.

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GRINDSTONES AND OILSTONES.

GRINDSTONES.

3. Composition.—In the case of grindstones, the cutting material is oxide of silica SiO_2, or *quartz sand*, as it is commonly called. The individual grains, in order that they may be in proper condition for cutting, must be sharp and angular. As found in nature, the grains are bound together either by a calcareous or lime cement, or by a silicate bond. This bond must be of such nature and strength that when the grains of sand become dull, the friction will tear them from the stone and thus uncover fresh, sharp grains for the work of grinding. Grindstones are simply natural sandstones of such texture that they are suitable for grinding operations.

4. Localities Where Grindstones Are Obtained. Many of the best grindstones used in the United States come from Berea, Ohio; Huron, Michigan; or from Grindstone Island, Nova Scotia. All these localities produce several grades of stones; the Nova Scotia stones are of all grades, but most of the Berea stones are rather coarse. There are also a few foreign stones used in the United States, most of which are known as Liverpool stones. The Liverpool stones vary in quality from medium to fine.

5. Action of Water On a Grindstone.—As grindstones cut more freely when wet, they are generally used with water. The function of the water is, further, to carry off the heat resulting from the friction between the stone and the tool, and also to wash away any particles of the stone and the steel that are dislodged by the grinding, and that, if not carried away, would tend to fill up the small spaces between the grains of the grindstone, and thus glaze its surface.

Grindstones are softer when wet than when dry, and, hence, a grindstone should not be left standing with only one side in water, as this will cause the wet side to be worn

away faster than the other when the stone is again used. This is a point that should be carefully noted.

6. Grade of Stone Required for Thin Work.—For grinding such pieces as mowing-machine knives, or any other piece having sharp thin edges that the stone must cut freely in order not to heat the work and draw the temper, it is necessary that the stone be soft enough to wear away with such rapidity as to keep the cutting particles at the grindstone surface always sharp.

7. Tool Rests for Grindstones. — For general tool grinding, a rest is commonly used. A temporary or movable rest, such as a block of wood, is regarded by some mechanics as being the most desirable, because in case the tool should catch, the rest would be thrown out, and the damage to the stone or to the operator would be less than if a solid, permanent rest were used.

8. Grindstone Mountings.—In mounting the stone, it is desirable to use iron flanges, about one-third the diameter of the stone, that are so hollowed on the inside as to bear upon the stone for an inch or more near their peripheries. It is, however, quite common to mount the stone without flanges, in which case the stone has a square hole in its center, and the shaft, which is also square where it passes through this hole, is surrounded by a bushing of wood or babbitt. The accompanying illustration, Fig. 1, shows a grindstone mounted upon a frame that has a trough for water, and, also, a truing device attached to it.

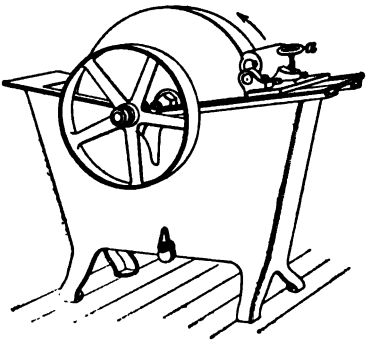


FIG. 1.

9. Automatic Truing Device. — The truing device shown on the frame in Fig. 1 works automatically, and can be applied while the grindstone is in

use, and removed when the stone has been trued. It is applied to the face of the stone that moves upwards. By turning the hand wheel *a*, the threaded roll is brought into contact with the stone and kept there until the stone is trued, the water, meanwhile, being left in the trough. When the screw threads become dull, they can be recut. Fig. 2 shows the truing device apart from the frame, *b* being the threaded roll.

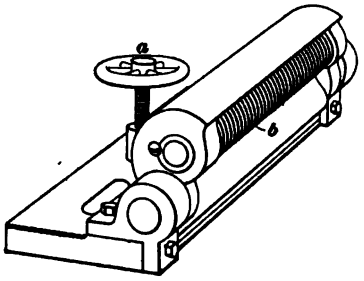


FIG. 2.

10. Truing by Hand.—All grindstones work out of true, and in the absence of an automatic truing device, the stone is sometimes trued by the use of an old file and a piece of gas pipe, or by using a piece of gas pipe alone. If the stone is badly out of true, it will be well to turn off the surface with the tang of an old file held firmly on a rest against the face of the stone, as shown in Fig. 3 (*a*). This will remove the high parts of the stone quickly, but will leave the surface quite rough. A smooth surface may then be produced by turning the face with a piece of gas pipe, the size that is commonly used being $\frac{3}{8}$-inch to $\frac{3}{4}$-inch pipe. The pipe is held on the rest but rolled across the face of

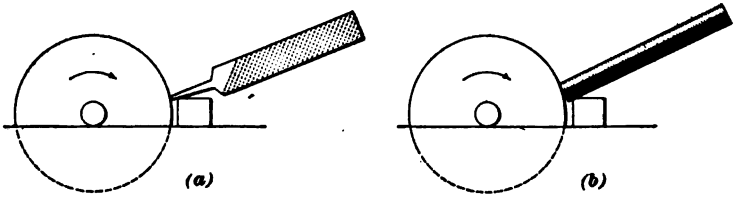


FIG. 3.

the stone, as shown at Fig. 3 (*b*). The finishing and turning on the stone is really done by the sand that is cut from the face of the stone and that lodges in the soft iron of the pipe, so that the process is actually that of stone cutting

stone. In both cases, the stone should revolve in the direction indicated by the arrow.

11. Speed Used in Grinding Tools. — For tool grinding, the grindstones are run at much less than their maximum speed. For machinists' tools, the peripheral speed should be 800 to 1,000 feet per minute; for carpenters' tools, 550 to 600 feet per minute. Another rule frequently given is to run the stone at the highest speed at which the water will not be thrown from its face by the centrifugal force. The maximum speed is limited by the safe working strength of the stone.

The following table of maximum speeds is given by some authorities, and should not be exceeded except when a very hard, strong stone is used, and then only when the stone is well mounted with strong flanges, and is so located that damage from bursting would not be likely to be very great. The number of revolutions given correspond to a periphery speed of nearly 3,400 feet per minute.

TABLE I.

TABLE OF MAXIMUM SPEEDS.

Diameter of Stone.	Revolutions per Minute.
8 feet	135
7 feet 6 inches	144
7 feet	154
6 feet 6 inches	166
6 feet	180
5 feet 6 inches	196
5 feet	216
4 feet 6 inches	240
4 feet	270
3 feet 6 inches	308
3 feet	396

12. Artificial Grindstones.—A few artificial grindstones have been made that have the advantage of being more uniform in texture than natural stones. At the present time, most of the artificial grinding disks are made of emery or corundum, and are generally known as *emery wheels*. They have largely taken the place of sandstones for grinding, except in some special lines of grinding, particularly where even a little heat injures the work, as in the grinding of glass lenses.

OILSTONES.

13. Composition.—Natural oilstones, like grindstones, are composed of quartz sand SiO_2, but the grains are finer and are bound together in a different manner. The cementing material or bond in oilstones is generally silica, and is more in the nature of a glass or vitreous bond than is the case with grindstones. In fact, most oilstone deposits are so seamed with thin veins of quartz that it is impossible to get any large stones or slabs, which is the principal reason why grinding wheels are not made of this material.

The oilstone is of such a nature that the particles worn from the stone are best removed by oil and the stone cuts best when supplied with oil. Generally speaking, sperm oil is the best grade to be used on oilstones, though a good grade of machine oil can also be used.

14. Kinds and Qualities.—The classes of oilstones on the markets in the United States may be generally divided into Arkansas stones and Washita stones. The Arkansas stones are very fine-grained and appear like white marble. They are used for sharpening the finer grade of instruments and produce remarkably keen, fine edges. The Washita stones are much coarser in grain, with the color sometimes white, but frequently having a yellow or red tinge. The Washita stone is coarser than the Arkansas and cuts more rapidly, but with greater delicacy than would ordinarily be expected from one having so coarse a grain.

The Washita stones are, as a rule, better for sharpening wood-working tools than the Arkansas stones, while the Arkansas stones are used more frequently in the machine shop. The Washita stones can be obtained in larger pieces than the Arkansas stones and are less expensive.

15. Artificial Oilstones. — Artificial oilstones are now on the market. They possess several advantages over the natural stones. Those sold under the name of *Indian oilstone* are composed of a peculiar grade of Indian corundum, and, hence, have very good cutting qualities. One special advantage is that some stones are manufactured having one coarse face and one medium face, i. e., one half of the stone is of one grade and the other half of another grade, thus giving the advantage of two stones with only one piece to look after. Then, too, the artificial stones can be made in special forms, such as slips, cones, etc., easier than natural stones. The artificial oilstones are also made in any size, and, as a consequence, the larger sizes are not extremely expensive, as is the case with the natural stones. The artificial oilstones are also made in the form of wheels similar to emery wheels, and either in the form of wheels or flat slips, they can be used with oil or water as a lubricant. At present they are manufactured in three grades: fine, medium, and coarse. The fine grade is approximately equivalent to the Arkansas stones, the medium grade to the Washita stones, and the coarse grade cuts freer and faster than either of the above.

GRINDING WHEELS.

ABRASIVE MATERIALS.

CORUNDUM.

16. Composition and Where Found.—Corundum is pure alumina, or oxide of aluminum. It is crystalline in structure, and has a hardness of 9, in this respect ranking, among natural minerals, next to the diamond.

NOTE.—In order to provide a convenient means of comparing the hardness of minerals, a comparative scale has been adopted in which 10 minerals are taken to represent 10 degrees of hardness, and all other minerals are compared with the members of this scale. The scale is as follows:

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorite.
5. Barite.
6. Feldspar.
7. Quartz.
8. Topaz.
9. Corundum or Sapphire.
10. Diamond.

The gem sapphire is sometimes used in the scale in place of corundum, but sapphire is only the gem form of crystallized corundum. Talc is the softest of the minerals of the scale and can easily be scratched with the finger nail, while diamond is the hardest substance known.

It is found in considerable quantities in Georgia and North Carolina, also in Canada; while small quantities have been exported from India. In Georgia and North Carolina, it occurs in masses in veins of rock, and also in beds in the granular form known as *sand corundum*. In the latter case it is mixed with clay and other impurities. In Canada, it is found quite uniformly distributed through large masses of rock that, when crushed, yields 10 per cent. to 20 per cent. of corundum crystals.

Good commercial corundum shows by analysis from 40 per cent. to 80 per cent. or even 90 per cent. of the thoroughly crystallized aluminum oxide Al_2O_3; from 5 per cent. to 25 per cent. of aluminum silicate and imperfectly crystallized aluminum oxide; from 2 per cent. to 6 per cent. of iron oxide; about the same amount of free silica; and from 1½ per cent. to 3 per cent. of water or other substances that are driven off at red heat.

17. Properties.—When corundum occurs in masses, it is either picked up on the surface of the mountain in boulders of various sizes, or it is uncovered by blasting away the rock. The mineral thus obtained is passed through crushers and then through rolls until it is reduced to grains of suitable size for making wheels, or for other abrasive purposes. Afterwards it is frequently treated by an abrading and washing process that removes the impurities from the grains or kernels of corundum. It is then

dried and graded by being passed over sieves of suitable mesh to give the sizes desired. These sizes range from Nos. 12 or 20 to 200.

18. Grading, and Meaning of Numbers Used.—The numbers by which the grain of corundum is designated are determined as follows: A No. 20 sieve, for example, is one that has 20 meshes to a lineal inch, and No. 20 emery is, theoretically, composed of kernels that will just pass through the meshes of a No. 20 sieve. Practically, the kernels of No. 20 are not all of a size, but are such sizes that the largest will just pass through a No. 20 mesh, and the smallest will not pass through the next smaller-sized mesh, which may be that of a No. 22 or 24 sieve, according as the grading is more or less close as to size. The numbers principally used for making abrasive wheels are from 20 to 80 or 100. The finer numbers are used for polishing.

EMERY.

19. Composition and Where Found.—Emery consists of corundum in combination with the protoxide of iron. The presence of the iron gives the mineral a dark color, and also makes the grains a little tougher and less brittle than the grains of pure corundum. In hardness, emery is generally rated about 1 degree lower than corundum.

The principal sources of commercial emery in the United States are the extensive emery mines at Chester, Massachusetts, and at Peekskill, New York; and in foreign countries, the island of Naxos, belonging to Greece, and the emery mines of Turkey, located near Smyrna. Good commercial emery has from 40 per cent. to 60 per cent. of solid grains, the remaining 60 per cent. to 40 per cent. being aluminum silicate, iron oxide, silica, water, etc. in proportions that vary with the kind of emery.

20. Preparation.—Emery is mined, crushed, cleaned, and graded in about the same manner as corundum, and is sold in the market as Chester emery, Naxos emery, and Turkish emery. It varies considerably in its degree of purity, there being a difference in the quality of the ore from different mines, and even from different parts of the same mine. The process of manufacture, and the skill and thoroughness with which the ore is treated for the removal of impurities, also have much to do with its degree of purity.

ARTIFICIAL ABRASIVES.

21. Carborundum. — The electric furnace develops such a high temperature that it offers opportunity for experiments to determine whether some artificial product may be produced that will take the place of emery and corundum for purposes of grinding. In 1893, Mr. E. G. Acheson produced in an electric furnace a substance that he named **carborundum,** which is the only artificial abrasive that has thus far been extensively used. It is manufactured in quite large quantities by The Carborundum Company at Niagara Falls. Abrasive wheels are made of this material by The Carborundum Company, but it is sold in the market for various purposes, though not for the manufacture of wheels.

Carborundum is carbide of silicon SiC, and is made by surrounding a small core or cylinder of pure carbon with a mass of coke and sand to which a little salt and sawdust is added. A powerful electric current is then passed through the carbon core, which, by its resistance to the current, becomes heated to a high temperature, and this temperature is communicated to the coke and sand surrounding it. At the high temperature thus obtained, the carbon and silicon unite and crystallize, and when the furnace is cooled and the core uncovered, it is found to be surrounded by a ring of brilliantly colored crystals of carborundum.

MANUFACTURE AND USE OF EMERY WHEELS.

22. Use of Term Emery Wheel.—In speaking of abrasive wheels, the common term "emery wheel" will include also corundum and carborundum wheels, except where some special quality requires particular mention of the cutting material of the wheel.

23. Parts of Emery Wheel.—An emery wheel consists of two essential parts; viz., the *emery*, or cutting material, and the *bond*, or matrix. The sharp points, or corners, of the grains of emery in the wheel constitute an indefinite number of cutting points or edges.

24. Bonds for Emery Wheels.—In order that these sharp and hard points may be effective in cutting away the material presented to them, the grains must be firmly held, just as a diamond point used for cutting glass must have a suitable setting. The bond, or matrix, of the wheel furnishes this setting for the grains of emery. It must be strong enough to form a wheel that will resist the centrifugal force due to the high speeds at which the wheels must be run to secure their greatest efficiency, and, also, must be hard enough not to wear away too rapidly and let the grains of emery loose before they have done their work. On the other hand, the bond must not be too hard, or it will not give way when the projecting corners of the grains of emery have been reduced by contact with the work, and the wheel will acquire a hard, smooth surface, with no cutting properties. The character and quality of the bond are, therefore, of great importance in the manufacture of emery wheels.

CLASSIFICATION OF EMERY WHEELS.

25. General Consideration.—Emery wheels may be classified with reference to the material used for bond, the principal varieties being as follows: (*a*) Wheels with a vitrified bond, known as *vitrified wheels;* (*b*) wheels with a

silicate-of-soda bond, known as *silicate wheels;* (*c*) wheels with a shellac bond, known as *gum* or *elastic wheels;* (*d*) wheels with a rubber bond, known as *vulcanite wheels;* (*e*) wheels with a celluloid bond, known as *celluloid wheels;* (*f*) wheels with a preparation of leather bond, known as *tanite wheels.*

26. Vitrified Wheels. — The material used for the bond in vitrified wheels is a mixture of certain clays and fluxes. When these clays have been thoroughly mixed with the emery in the proper proportions, usually by means of water, the mass is dried sufficiently to allow of its being formed into a wheel. This wheel is then put upon a fire-brick disk and placed in a kiln where the temperature is raised until the clay and fluxes begin to melt (probably about 3,000° F.), so that the whole wheel becomes one homogeneous mass. It is then allowed to cool, the bond becoming essentially the nature of glass. This vitrified bond, thickly studded with grains of emery, is a vitrified emery wheel. The *Norton*, the *abrasive*, the *sterling*, the *Grant*, and the *safety* are examples of vitrified wheels.

27. Silicate Wheels.—When silicate of soda is used as a bond, this material, after being prepared and mixed with the emery, is tamped into a mold, and the bond hardened by drying in an oven at a moderately low temperature, say 325° to 400° F. The *Detroit* and the *Scranton* are examples of silicate wheels, though similar wheels are made by several other companies.

28. Shellac Wheels. — Shellac wheels are made by mixing the emery with a preparation of shellac, forming the wheels in molds, and hardening them by heat at a low temperature, say from 300° to 400° F.

29. Vulcanite Wheels.—In the manufacture of vulcanite wheels, the preparation of rubber that forms the bond is filled with emery and the mass made homogeneous by being repeatedly passed between rolls. In the case of thick wheels, several sheets, or layers, from the rolls may be used

to form a single wheel. The wheel is then subjected to hydraulic pressure and afterwards placed in a vulcanizer, where it is exposed for some time to a degree of temperature sufficient to harden the bond. When the wheel is used, the heat generated melts away the bond fast enough to loosen and drop out the kernels of emery as fast as they become dull, thus keeping the wheel sharp.

30. Celluloid wheels are made by but one company. They are strong and can, therefore, be run at high speeds. Also, very thin wheels of this type may be used with safety.

31. Tanite Wheels.—Tanite is a substance that was invented and first used for the manufacture of buttons, combs, and fancy articles. When it was found to be a suitable bond for an emery wheel, the Tanite Company became known as the manufacturer of tanite emery wheels. Tanite is hard and strong at low temperatures, but soft and plastic at high temperatures. Hence, a tanite wheel has somewhat of the qualities of a vulcanite wheel; that is, when the wheel is used the heat softens the bond at its surface and releases the dull kernels of emery.

PREPARATION OF EMERY WHEELS.

32. Bushing Emery Wheels. — In ordering emery wheels, one of the dimensions that should be given is the diameter of the spindle on which the wheel is to run. The wheel is, therefore, made with a hole in the center somewhat larger than the largest spindle that is used to carry a wheel of its size, and when an order is received, the wheel is "bushed" to the size of spindle for which it is ordered.

The bushing is usually of lead. The wheel is placed in a horizontal chuck with a bushing spindle of the required size at the center of the chuck, and melted lead poured into the annular space between the bushing spindle and the wheel. As the emery wheel when sent out must have a perfectly cylindrical surface, it is necessary in ordinary methods of truing that the bushing be done before truing the periphery of the wheel.

33. Truing Emery Wheels.—Purchasers of emery wheels generally demand that the wheels be not only round, but of uniform thickness. In most processes of making wheels, the shape of a wheel changes slightly when the bond hardens. Sometimes the wheel warps, but it always shrinks an uncertain amount. It is therefore necessary that the wheels be trued both on their faces, to make them of uniform and correct thickness, and on their peripheries, to make them true cylinders. Inasmuch as the wheel is made to cut other substances, rather than to be itself rapidly reduced in size, the truing is one of the most difficult and expensive processes involved in its manufacture.

There are two principal methods used in truing. One is to cut away the material of the wheel by means of some harder substance than the wheel itself, as the diamond. This method is expensive, and is impracticable for large and coarse wheels. The other method is to use a dressing tool made of steel or chilled-iron disks, either flat or conical, that are free to revolve on a central spindle. This tool is pressed against the revolving wheel, and as the disks of this dressing tool revolve in rolling contact with the emery wheel, the kernels of emery are dislodged, the action of the disks of the tool being somewhat like that of a quick, sharp blow.

The action of the disk-dressing tools upon an emery wheel is similar to that of the stone-cutter's point tool, or chisel, used in dressing stone; and just as a chisel, or point tool, can be made to cut stone much harder than itself, so the dressing tool can be made to break the projecting kernels out of the rapidly revolving emery wheel, thus giving the wheel an even surface.

34. The truing tool may be used as part of an automatic machine, or it may be used as a hand tool. The manufacturer, in preparing wheels for the market, frequently uses the automatic machine. The user of emery wheels should have a hand dresser, to true the wheels whenever they wear a little out of round. Fig. 4 illustrates three different kinds of hand tools for truing and dressing the

peripheries of wheels, all of which are similar in their action. They are composed of a handle *a*, carrying a number of

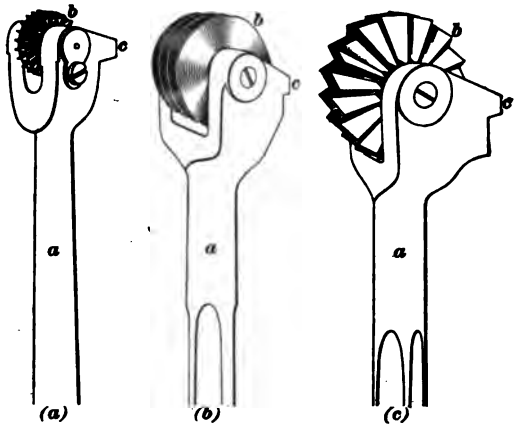


FIG. 4.

hardened disks *b*, which may be brought into contact with the surface of the emery wheel. The projection *c* serves as a support for the tool when in use.

GRADING EMERY WHEELS.

35. Emery wheels are graded by a process in which the hardness of the wheel relative to some arbitrary standard is determined. The manufacturer grades each wheel as closely as possible, and publishes in his catalogue an explanation of his system of grading. The buyer, in ordering, must either know the grade of wheel that will do his special work, or he must describe the work and allow the manufacturer or dealer to select it for him. On many kinds of work, a slight variation from the correct grade will cause the wheel to give poor results; the very best wheel for one kind of work may be useless for another kind or quality of metal. The user of emery wheels should, therefore, exercise much judgment in the selection of wheels in order that they may be adapted for the purposes for which they are to be used.

TABLE II.

TABLE FOR SELECTION OF GRADES.

Class of Work.	Number of Emery or Degree of Coarseness Usually Furnished.	Grade Letters or Degrees of Hardness Usually Furnished.	Grade Letters or Degrees of Hardness Furnished in Exceptional Cases, Sometimes SOFT AS	Sometimes HARD AS
Large cast-iron and steel castings	16 to 20	P to Q	O	U
Small cast-iron and steel castings	20 to 36	O to P		Q
Large malleable-iron castings	16 to 20	Q to R	P	W
Small malleable-iron castings	20 to 30	P to Q	O	U
Chilled-iron castings	16 to 20	R to T	Q	U
Wrought iron	16 to 30	P to Q	O	R
Brass and bronze castings	20 to 30	O to P		R
Rough work in general	16 to 30	P to Q	O	R
General machine-shop use	30 to 46	O to P		
Lathe and planer tools	30 to 46	N to O	M	P
Small tools	46 to 100	N to P		
Wood-working tools	36 to 60	M to N	L	O
Twist drills (hand-grinding)	36 to 60	M to N		
Twist drills (special machines)	46 to 60	G to J		
Reamers, taps, milling cutters, etc. (hand-grinding)	46 to 100	N to P		
Reamers, taps, milling cutters, etc. (special machines)	46 to 60	H to K		
Edging and jointing agricultural implements	20 to 30	Q to R		W
Grinding plow points	20 to 30	P to Q		U
Surfacing plow bodies	20 to 30	N to O	M	P
Stove mounting	20 to 36	P to Q		
Finishing edges of stoves	30 to 46	O to P		
Drop forgings	20 to 30	P to Q		
Gumming and sharpening saws	36 to 60	M to N	L	O
Planing-mill and paper-cutting knives	30 to 46	J to K	I	M
Car-wheel grinding	20 to 30	O to P	N	R

36. Makers of vitrified wheels use as a system of designating grades, the letters of the alphabet, the first letters indicating the softer wheels. To give an idea of the relations of the grades to the work to which each grade is adapted, Table II, published by The Norton Emery Wheel Company, is given. This table agrees quite closely with the system of grading that is used by most of the makers of vitrified wheels.

37. Testing Emery Wheels.—Emery wheels sometimes break or burst while running, which accident, in the case of a large wheel, is liable to do considerable damage, besides endangering the life of the workman using it. In most cases where a wheel breaks when running, a careful examination of the conditions reveals some adequate cause other than the inherent weakness of the wheel. To be sure that the wheel is sound and strong when it leaves the factory, the manufacturer should test it by running it for a short time at a higher rate of speed than will be required when the wheel is in actual use.

38. The machine used for such testing must have a cover for the wheel that will arrest the pieces if the wheel should break. The centrifugal force acting to break a wheel is proportional to the square of the number of revolutions made by the wheel; therefore, if the speed is doubled, the centrifugal force is quadrupled. It is customary, in testing wheels for strength, to run them at nearly double their working speed, such a test being almost sure to break a wheel if it is not free from cracks or other defects.

39. The following table shows the number of revolutions per minute for specified rates of periphery speed, also the stresses per square inch on vitrified wheels at the specified rates of speed. The usual working surface speed is from 5,000 to 6,000 feet per minute; the number of revolutions corresponding to these surface speeds are given in the table.

TABLE III.

SPEEDS OF GRINDING WHEELS.

Diameter. Inches.	Surface Speed of 1,000 Feet.	Surface Speed of 2,000 Feet.	Surface Speed of 3,000 Feet.	Surface Speed of 4,000 Feet.	Surface Speed of 5,000 Feet.	Surface Speed of 6,000 Feet.	Surface Speed of 7,000 Feet.	Surface Speed of 8,000 Feet.	Surface Speed of 9,000 Feet.	Surface Speed of 10,000 Feet.
	Stress per Square Inch, 3 lb.	Stress per Square Inch, 12 lb.	Stress per Square Inch, 27 lb.	Stress per Square Inch, 48 lb.	Stress per Square Inch, 75 lb.	Stress per Square Inch, 108 lb.	Stress per Square Inch, 147 lb.	Stress per Square Inch, 192 lb.	Stress per Square Inch, 243 lb.	Stress per Square Inch, 300 lb.
	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.	Revolutions per Minute.
1	3,819.71	7,639.42	11,459.13	15,278.83	19,098.54	22,918.25	26,737.97	30,557.68	34,377.39	38,197.10
2	1,909.85	3,819.71	5,729.56	7,639.41	9,549.27	11,459.12	13,368.98	15,278.84	17,188.69	19,098.55
3	1,273.24	2,546.47	3,819.71	5,092.94	6,366.18	7,639.41	8,912.66	10,185.89	11,459.13	12,732.36
4	954.93	1,909.85	2,864.78	3,819.70	4,774.63	5,729.56	6,684.49	7,639.42	8,594.34	9,549.27
5	763.94	1,527.88	2,291.83	3,055.76	3,819.70	4,583.65	5,347.59	6,111.54	6,875.48	7,639.42
6	636.62	1,273.23	1,909.85	2,546.47	3,183.09	3,819.70	4,456.32	5,092.94	5,729.56	6,366.18
7	545.67	1,091.35	1,637.02	2,182.69	2,728.36	3,274.03	3,819.71	4,365.38	4,911.05	5,456.73
8	477.46	954.93	1,432.39	1,909.85	2,387.31	2,864.78	3,342.24	3,819.71	4,297.17	4,774.63
10	381.97	763.94	1,145.91	1,527.88	1,909.85	2,291.83	2,673.79	3,055.77	3,437.74	3,819.71
12	318.31	636.62	954.93	1,273.23	1,591.54	1,909.85	2,228.17	2,546.47	2,864.78	3,183.09
14	272.84	545.67	818.51	1,091.34	1,364.18	1,637.02	1,909.85	2,182.69	2,455.53	2,728.36
16	238.73	477.46	716.19	954.92	1,193.66	1,432.39	1,671.12	1,909.85	2,148.58	2,387.32
18	212.21	424.41	636.62	848.82	1,061.03	1,273.24	1,485.44	1,697.65	1,909.85	2,122.06
20	190.99	381.97	572.95	763.94	954.92	1,145.91	1,336.90	1,527.88	1,718.87	1,909.85
22	173.62	347.24	520.87	694.49	868.11	1,041.74	1,215.36	1,388.98	1,562.61	1,736.23
24	159.15	318.31	477.46	636.61	795.77	954.93	1,114.08	1,273.23	1,432.39	1,591.55
30	127.32	254.65	381.97	509.29	636.61	763.94	891.26	1,018.59	1,145.91	1,273.23
36	106.10	212.21	318.31	424.42	530.51	636.62	742.72	848.82	954.93	1,061.03

GRINDING.

40. Applications of Grinding. — Emery wheels are used for grinding all kinds of metals; also glass, porcelain, rubber, wood, and leather, including the dressing of kid skins that are used for making gloves. They are made in a great variety of sizes that range from the small wheel used by the dentist and weighing a fraction of an ounce, to wheels 3½ feet or more in diameter and weighing 1,000 pounds. They are also made in a variety of shapes for special machines and work. Iron and steel castings, chilled rolls, hollow ware, stove fittings, plow points, car wheels, armor plate, tools for cutting metals and wood, and such special tools as cutters, reamers, saws, etc.; also spheres and cylinders for roller bearings, and the interior surfaces of cylinders that must be accurately formed, such as the "Triple" cylinders for the Westinghouse air brake, are all ground with emery wheels.

The grinding machine is used successfully on the finest work and also on the coarsest. A fine wheel will remove .00001 of an inch of material from a cylinder, while a coarse wheel will grind inequalities from the rough casting with surprising rapidity and apparent ease. Many persons having seen the rapidity with which a large coarse emery wheel will remove irregularities from a casting have attempted to substitute emery wheels for the lathe tool for roughing out work, but as yet this method has not been a success, as it always takes more power, and up to the present time has cost more to reduce metal to dust than to chips. By the use of very large, heavy, automatic machines using large and heavy wheels, it may be possible to reduce the labor and wheel costs so low that it will enable the grinding machine to remove large amounts of stock, not only faster, but cheaper than it can be done in the lathe.

41. Object.—The processes of modern grinding may be said to have three principal objects; viz.: *First*, the removal, or cutting away, of stock from the piece to be ground. *Second*, the bringing of pieces to exact specified

dimensions. *Third*, the production of a satisfactory finish upon the surfaces ground.

42. Possibilities. — The latest improved automatic grinding machines are demonstrating that large wheels driven on rigid machines and with sufficient power will, in many cases of cylindrical grinding, remove a considerable amount of stock cheaper than it can be removed in a lathe. Grinding machines are, therefore, likely to come into more general use, because they can successfully compete with the lathe where accurate work and smooth finish are required. Indeed, the field for grinding by automatic machines has recently been greatly enlarged by improving the design of the machine and using larger wheels.

POLISHING AND BUFFING.

POLISHING.

43. Object.—Polishing differs from grinding in that it is not done to remove material or change the size and shape of the work, but simply to create a bright or smooth surface.

44. Polishing Wheels and Belts.—Polishing wheels are usually made by covering the periphery of wooden wheels with leather and gluing to this leather a coating of emery. This is done by coating the leather with hot glue, and before the glue becomes dry rolling the wheel in loose emery until the emery ceases to adhere to it. When used, such wheels are trued, in a sense, by holding an oilstone or other hard substance against them while they are being run. This levels the rough or projecting places.

Flat and curved surfaces are polished on the periphery of wheels and more irregular objects are polished by holding and turning them against leather belts covered with emery and running over pulleys, these belts being wide or narrow, tight or loose, according to the shape of the work.

When polishing, the work is held in the hand and moved in such a manner that the desired finish is produced. Much practice is required to polish fine work, as it is a matter of skill and touch on the part of the workmen.

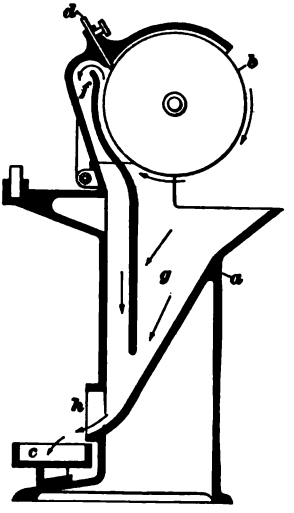


FIG. 5.

45. Enclosed Polishing Wheel. — Polishing-wheel machines are usually of a primitive nature. Sometimes they are composed simply of two uprights in which are held wooden plugs having holes in their ends that receive the points of the polishing spindle. There are, however, a few modern machines for polishing, one of which is illustrated in Fig. 5. The interior of the base *a* is so formed that the air-current caused by the rotation of the wheel when running will remove all dust caused in polishing and deposit it on the floor behind the machine or in the water tank *c*. The wheel *b* rotates in the direction indicated by the arrow. At the back a shield *d* is so arranged that it can be adjusted to almost touch the face of the wheel. This shield stops the current of

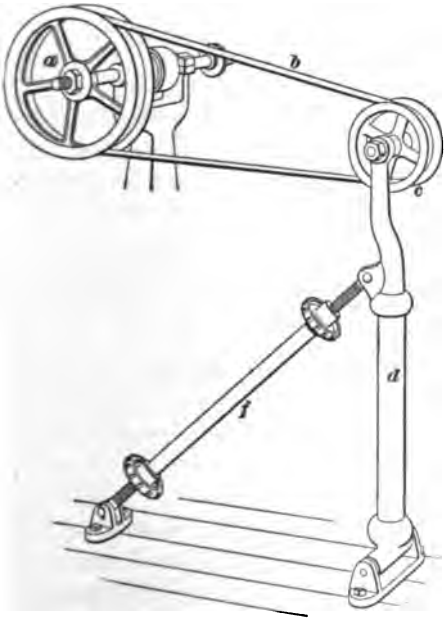


FIG. 6.

air rotating with the wheel and turns one current downwards through the passage *f*, while another current passes downwards through the passage *g*, but both air-currents are discharged at the back of the machine through the opening *h*. This machine was devised to polish small work. The wheels used in it are covered with leather and coated with emery.

46. Belt Polishing Machine.—Fig. 6 illustrates one form of mount for a polishing belt. In this case, a pulley *a* has been mounted on one end of an ordinary buffing-wheel or grinding-wheel arbor. The belt *b* passes over this pulley and the outer end is carried on the pulley *c*, which is supported upon a swinging arm *d* that is controlled by a brace *f*. By means of the brace *f*, the tension on the belt *b* may be regulated. This belt is coated with glue and emery, or any other suitable polishing material.

BUFFING.

47. Distinction Between Polishing and Buffing. Sometimes buffing and polishing are considered one and the same thing, but it is well to make a distinction between them at the point where the finish becomes grainless.

48. Buffing Wheels.—The buffed or grainless finish is obtained by means of soft wheels. These wheels are sometimes made of felt covered with emery, but usually they are formed of layers of cotton cloth that are cut into round blanks about 12 inches in diameter, which have a hole in the center. These round blanks are piled one above the other until there are enough to form a wheel from 2 to 4 inches thick. These are then placed on the arbor of the machine and bound together at the center by collars and a nut. The larger these collars are, the harder will be the wheel when running; the smaller the collars, the softer will be the wheel when running.

It should be understood that when this wheel that consists of layers of cotton cloth is in place on the arbor of the machine, the edges of the cloth are presented to the work, or form the periphery of the wheel. In use, this wheel is revolved (if 12 inches in diameter) from 4,000 to 6,000 revolutions per minute, according to the practice of the operator who may be using it.

49. The object of using cloth in this manner is to give a yielding wheel into the periphery of which the operator can press the work, which usually is irregular. In this way the cloth is made to rub every corner and curve of the work and the lines of its motion are in all directions, thereby not only polishing all corners and curves, but also giving a grainless surface.

50. Cutting or Polishing Material Used in Buffing.—The cutting or polishing material is used in the form of a cake that is made by compressing tallow, or other heavy grease, together with emery, crocus, flour emery, rouge, and any other material that may be in vogue with the particular operator, some using one kind and some another; the coarser material is used for roughing and the finer material for finishing and "coloring," as it is known in the workshop. This material is applied to the wheel by holding it firmly against the edges of the cloth, as the wheel revolves, until the edges become saturated; it is also applied from time to time as the operator wishes to change the cutting quality of the wheel.

51. Applications of Buffing. — Buffing is used for plated ware and for the peculiar surface that is common on bright vases, culinary articles, and lacquered surfaces. Much buffing is done by first cutting down with a rough material on the wheel, then finishing ready for plating. In the workshop this finishing operation is called *coloring*. In some of the finer grades of work, this is accomplished by holding it against a very soft cotton-cloth wheel that has no cutting material upon it. If the pressure and speed are

suited to the substance of which the article is made, a very bright surface will be produced.

It is a well-known fact that with plated ware the perfection of the surface after plating will never be greater than the surface on which the plating is deposited. After the article is plated, it is again taken to the soft buffing wheels and colored, which removes all stains from the plating bath and gives that peculiar luster that the operator calls "color."

Some work is first polished and then buffed, but in such cases the material is usually hard, such as steel, while brass and softer metals are not so treated.

52. Buffing-Wheel Mount.—Fig. 7 illustrates a light buffing-wheel mount that may also be used for small emery wheels. A rag wheel is shown on the left-hand spindle at *a*. In the style shown, the wheel is mounted on a bench stand. Similar wheels are built that are mounted on posts that stand on the floor. The machine is driven by a belt that runs on the pulley *b*, and has provision for a second wheel at *c*.

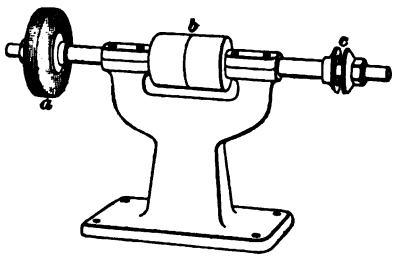


FIG. 7.

53. Brush Wheels. — For polishing purposes, wheels are frequently made that are surrounded by bristle brushes, or brushes made of other materials. In using these wheels, the material is applied to the brush either in the form of a wash or a wax, as in the case of buffing wheels or rag wheels. Brush wheels are more expensive than rag wheels and are not extensively used in machine shops.

54. Leather Wheels.—Wheels for polishing purposes are frequently cut from leather. For very small wheels, disks may be cut from thick saddle skirting, while when larger disks are required they are cut from walrus hide,

which can be obtained an inch or more in thickness and makes an excellent polishing wheel. The polishing material is usually mixed with oil or water, oil being preferred.

SELECTION OF GRINDING WHEELS.

55. General Remarks. — When selecting grinding wheels, it is well to understand that the smoothness of the surface required on the work depends on other conditions as well as the size of grains of which the wheel is composed. A fine-grained wheel does not produce a fine surface simply because the wheel is fine. In fact, it may produce a very coarse surface, and a coarse-grained wheel may produce a fine surface, when of the right grade and used at a speed best adapting it to the material being ground.

56. Grading of Grinding Wheels. — Emery and corundum wheels are made in different grades of hardness, and according to the standards of the Norton Emery Wheel Company, the grade of vitrified wheels is denoted by letters, A being the softest. The grades most commonly used are J, K, L, M, N, O, P, and Q. The grades of elastic or gum wheels are denoted by numbers, which range from 0 to 6, each number being $\frac{1}{4}$ larger than the preceding one; viz., 0, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, etc. Numbers 1 to 5 are those most commonly used.

Other companies have other systems of grading. Some grade their wheels from A to Z, A being extremely soft and Z extremely hard. The Carborundum Company grade their wheels from D to V, D being hard and V being very soft.

57. Relation Between Grade of Wheel and Work. — Hard-grade wheels retain their particles longer than softer ones; therefore, the softer grades are said to *cut sharp*, because the particles are torn out by the act of grinding before they become dull, and thus new ones are constantly being exposed to the work. Some kinds of work

require that these particles shall be torn out before they become at all dull, while other kinds of work require that they shall be retained until they become quite dull and smooth. Between these extremes, there is a great variety of work that requires a variety of grades of wheels.

Different materials and different shapes of work require different sizes of grain combined with different bonds and grades of hardness. In general, the harder that the material to be ground is, the softer must the wheel be, and the coarser may it be. With steel, the hardness of the wheel varies inversely with the softness of the material that is to be ground. Brass, copper, and rubber require soft wheels, and rubber very coarse ones. Hardened steel, cast iron, and chilled iron require soft wheels in order that the particles of emery and corundum may be broken out as they become dull and thus constantly present new ones to the work. Brass, copper, and rubber require soft wheels in order that the material being ground may not adhere to the wheel, but that the particles of emery may be torn out before the brass or copper can adhere. Soft steel requires a harder wheel than hardened steel, because the particles of emery are not dulled so soon and, entering deeper into the work, are torn out more readily. Hardened steel, cast iron, and chilled iron require soft wheels because these materials dull the particles of emery and corundum very quickly, making it necessary to throw them away rapidly.

58. Glazing.—When grinding hardened steel with a wheel that is too hard, the wheel will be worn bright and smooth and will cut but little. This is known as *glazing*. When soft steel is ground with a wheel that is too hard for the work, the wheel will fill with steel; for, since the particles remain sharp and enter deep into the soft steel, they cause the steel to adhere to them, especially if there is considerable pressure on the wheel. Fine-grained wheels when hard fill and glaze sooner than coarse ones of the same grade; and, when soft, wear away faster than coarse ones of the same grade when cutting the same depth.

HAND GRINDING.

59. General Consideration. — The term **hand grinding** is generally understood to cover those operations in which the work is held by hand, pressed against the emery wheel, and moved about either with or without the aid of a rest. There is a class of machines in which the work is large and stands still, while the emery wheel, which is mounted in a swinging frame, is moved about so as to grind the surface of the work.

60. Simple Hand Grinding Machine.—The grinding machine used in foundries for smoothing castings, and which is illustrated in Fig. 8, is perhaps the most common type of a hand grinding machine. These machines are made in a great variety of sizes, carrying wheels from 3 inches to 36 inches in diameter. The style shown is provided with

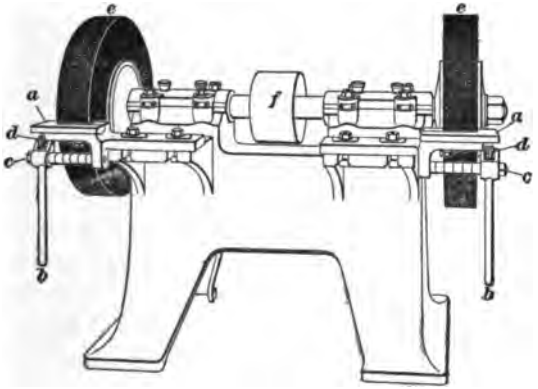


FIG. 8.

rests *a* upon which the work may be placed while it is being ground. For truing emery wheels, truing devices are permanently attached to the machine and shown below the rests, *c* being the axis on which the device works, *d* the truing wheel, and *b* the handle by means of which it is controlled. Whenever the wheel gets out of true, the truing device can be brought into contact with the face of the

wheel and moved across the face on the axis *c*, thus quickly truing the surface of the wheel *e*. The wheels *e* are driven by means of a belt on the pulley *f*.

In some cases, similar machines are used where considerable skill is required to produce the work, but as a rule this type is used only for comparatively rough work.

HAND SURFACING MACHINES.

MACHINES EMPLOYING EMERY WHEELS.

61. Table Machine. — The machine illustrated in Fig. 8 is intended for rough work. Where approximately flat surfaces are required without special regard being paid to the angles between the faces, a machine of the class illustrated in Fig. 9 may be employed. The illustration shows one bearing and one emery wheel of a machine provided with a surfacing table. The emery wheel *a* is mounted on a shaft *b* driven by a belt on the pulley *d*, one bearing for the shaft being carried by the bracket *c*. Above the emery wheel is mounted a table *e* through which the upper face of the wheel projects. As shown in the illustration, the table is provided with an adjustable fence *f* for guiding the work on the surface. The table *e* can be adjusted by means of the screw shown at the front of the table, to make allowance for wear in the emery wheel or to adjust the depth of cut taken. This machine will produce approximate flat surfaces and is very useful for removing

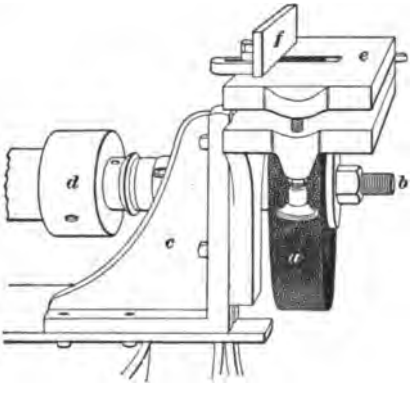


FIG. 9.

rough parts from flat surfaces, but is not especially adapted for producing correct angles. The machine is limited to work of such a size that can be easily handled and placed upon the table.

62. Swinging-Frame Machine.—Where large work is to be ground or polished, as, for instance, portions of engine-frame castings and cylinders, and similar work that frequently requires finishing, and where the work is of such great size that it would be impossible to take it to the emery wheel, a machine of the class illustrated in Fig. 10

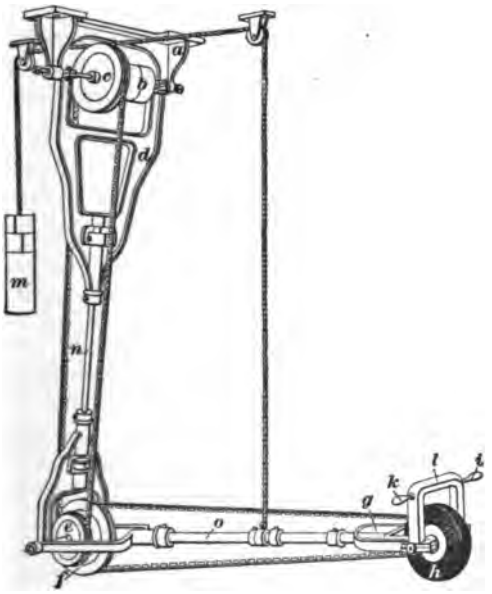


FIG. 10.

may be employed. This machine consists of a bracket *a* fastened to the ceiling that carries the countershaft on which are placed tight and loose pulleys *b* and the pulleys *c*. This countershaft is driven by a belt on the pulley *b*, while the emery wheel is driven by a belt on the pulley *c*, which drives the pulley *e*, which is permanently attached to the pulley *f*. The belt on the pulley *f* drives a pulley on the emery-wheel

shaft, thus imparting power to the emery wheel *h*. The swinging frame *d* is supported from the countershaft bearings and the swinging frame *g* is counterbalanced by means of a weight *m* and a suitable rope passing over the pulleys, as shown. The emery wheel *h* is mounted on a shaft at the end of the swinging frame *g* and is provided with a yoke *l* and handles *i* and *k*, by means of which its motion can be controlled. The connecting portion *n* below the swinging frame *d* is so arranged that it can swivel in the frame *d*, and the portion connecting the swinging frame *g* with the shaft carrying the pulleys *e* and *f* is also arranged so that it can swivel. The result is that the emery wheel *h* can be turned to any angle or into almost any plane, either horizontal or vertical. This enables the operator to grind both surfaces and edges of the work, or to round corners. This class of machine has found a great field of usefulness, especially in the finishing departments of shops producing rather large work, but considerable skill on the part of the operator is required to produce a smooth surface with it.

63. Upright Surface Grinding. — Flat work may also be ground by holding it against the side of an emery wheel similar to that shown in Fig. 8, but this is rather an awkward and difficult method of procedure and, hence, emery wheels have been mounted on vertical axes so that the work may be placed on the side of the wheel and thus ground flat. Such machines are called *upright surface grinders* and are used to a considerable extent on some classes of work.

DISK GRINDERS.

64. All machines using emery wheels have the common disadvantage that it is difficult to keep the surface of the emery wheel true; hence, accurate work cannot be produced by this class of hand grinding machines without placing the machines under special runners and providing truing devices for the wheels. To overcome this difficulty, the **disk surface grinders** have been brought out. A

type of disk surface grinder is illustrated in Fig. 11. The grinding is done by means of emery cloth secured to the steel disks *a*. These disks are from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch thick, are ground perfectly true and parallel, and are provided with a spiral groove on the side running from the center to the periphery. Emery cloth is then glued or cemented upon each side of these disks. In cementing the emery cloth on, it is pressed firmly against the disk so as to bed it into the groove. This provides a space into which any particles of emery or grinding dust will pass and so prevent them from scoring the surface of the work.

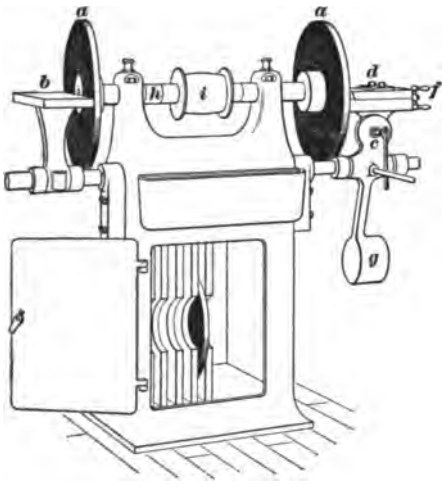


FIG. 11.

The disks are used until one side is dull and are then reversed and used until the other side is dull, when they are replaced by other disks and the worn ones recovered. The machine shown illustrates two principles of grinding that may be employed. At the left-hand side of the machine there is a simple flat table *b* whose upper surface is scraped at exactly right angles to the disk; by holding any flat surface upon this table, a surface at exactly right angles to it can be ground by the disk.

65. The manufacturers claim that it is easily possible to grind small work within the limit of .001 inch on these machines. When it is desired to grind at any other angle than a right angle, an attachment similar to that shown at the right-hand side of the illustration may be used. This is provided with a graduated circle on the piece *c* by means of

which the table can be set at any angle to the disk. It is also provided with a sliding guide *d* controlled by the handle *f* which operates the feed-screw. By providing a stop or indicator disk upon the handle *f*, the exact thickness to which the work is ground can be gauged within .001 of an inch; and by means of the graduated circle on the piece *c*, the angle between the faces can be accurately determined. This head is also provided with a balance weight *g* by means of which it can be arranged to oscillate within limits, thus swinging the work back and forth across the face of the grinding disk and so reducing the liability of producing scratches upon the surface. The disks are carried upon the shaft *h* driven by the pulley *i*. The machine is mounted upon a substantial base, provided with a cupboard for containing the grinding disks.

The disk grinding machine does not replace any particular machine tool in the shop as much as it serves to do work that is ordinarily done by filing, but it will be found possible to do a large amount of work that is ordinarily done at the bench on a machine of this class.

TOOL GRINDING.

HAND TOOL GRINDING.

66. General Consideration.—Under the heading of hand grinding may be classed the grinding of tools for turning and planing metal. A number of different machines are made for this purpose on which emery wheels are used; some of these grind dry and some wet. The wet grinding wheels may be divided into two classes, those that receive their water from the pump system and those in which the wheel runs in a trough or bath into which water may be admitted. The dry grinding machines are comparatively little used for tool grinding, because they are liable to draw the temper of tools; hence, only the wet grinding machines will be described.

WET GRINDING MACHINE.

67. Methods of Supplying Water.—A representative tool-grinding machine intended for wet grinding is illustrated in Fig. 12. This machine is shown because it is arranged to provide for a supply of water without the use of pumps or pipes, and, also, because it has a truing device arranged in a wheel guard. In Fig. 12 a section of the

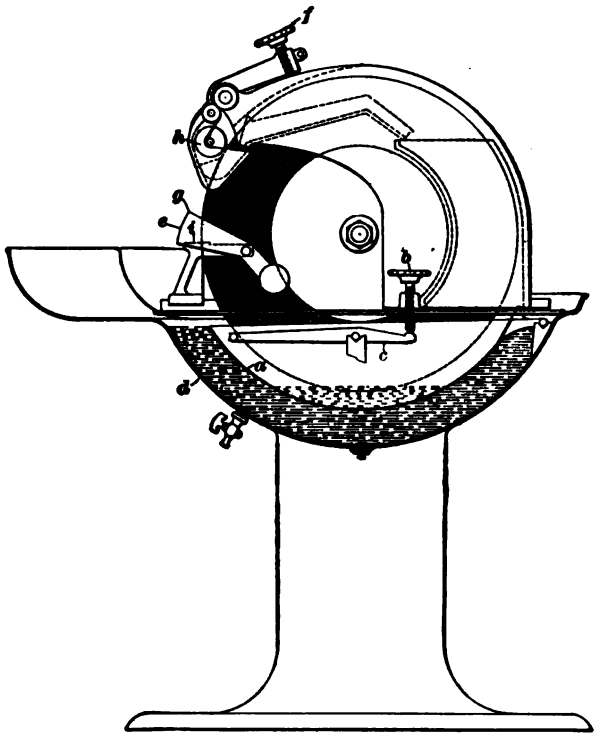


FIG. 12.

machine is illustrated, showing the manner in which the water is applied. The water tank *d* is filled with water while the water trough *a* is raised to its highest level by means of the screw *b* and the lever *c*, this water trough being pivoted at one end. The water trough *a* surrounds the lower part of the emery wheel and when in its highest position

prevents water from wetting the wheel; as the trough *a* or its forward end is lowered, it sinks into the surrounding water and allows it to flow in around the wheel. The trough is lowered sufficiently to obtain the amount of water desired by the operator; the wheel throws the water out at the rear, but an equal amount, of course, runs in at the forward end of the trough, thus keeping the supply constant.

68. Truing Device.—The truing device consists simply of a thread roll *h* mounted on the end of a rocking lever, so that the operator can force it against the revolving wheel by means of the screw *f*. This truing device is always ready for use.

69. Tool Rest.—The tool rest and guard in this style of machine are shown at *i* and *e*. This rest is surrounded by a guard *e* so arranged with a balance weight that it normally occupies the position shown. When the operator wishes to grind a tool, he places it on the point *g* and presses it downwards until the tool comes in contact with the rest *i*. When the grinding is being done, the guard rises and prevents water from spattering out in front, no matter how large an amount of water may be supplied to the wheel.

MACHINE TOOL GRINDING.

TYPE OF MACHINES.

70. General Consideration.—With the growth of machine manufacturing, replacing as it does the older method of machine making, it has become the practice in large machinery establishments to manufacture the lathe and planer cutting tools in large lots. These tools are all ground to the correct shapes and are ready for the workman to use. The old ones are reground and sharpened to the standard forms and then placed in the tool room, where they may at any time be obtained by the workman.

The shapes of the tools vary in different establishments, but usually each establishment fixes on standard shapes for all their cutting tools and the operator follows the blueprint of standards that is generally placed on the holders shown at the right of the machine in Fig. 13.

This matter of machine tool grinding has become of so much importance in the economy of cutting tools that it may be dignified as a trade, requiring (as relating to the establishment of standards and the grinding of these tools commercially) considerable study and care. It is probable that within a few years operators who are skilled in the art of tool shaping and grinding as related to the economy of cutting metal will be in demand.

There are two general classes of machines employed for this purpose, one of which uses an ordinary emery wheel and grinds the tools on the face of the emery wheel, while the other employs a disk wheel and grinds the tools on the flat face of the disk. The machine manufactured by Wm. Sellers & Company, Philadelphia, is a good representative of the first class, and that manufactured by the Gisholt Machine Company, Madison, Wisconsin, is a good representative of the second class.

71. Sellers Grinding Machine. — The Sellers machine shown in Fig. 13 is called a *universal tool-grinding and shaping machine.* This machine is so constructed that, with its fixtures and attachments, the accuracy of the form to be ground is not dependent on the skill of the operator, but is obtained by placing the various holders and attachments at the angles required, these being graduated and marked so that if the operator places them at the right graduation and angles, the accuracy of the grinding will be insured. When the tools are placed in the various holders, the operator moves them against the wheel by the use of a lever shown at *a*, Fig. 13. Water is supplied to the emery wheel by means of a rotary pump, and on one side of the machine is attached a diagram of instructions for obtaining the standard shapes. This diagram is shown at *b*, Fig. 13.

The Sellers machine is designed to present a line contact between the emery wheel and the work being ground. The makers believe that it is absolutely necessary, in order to efficiently grind steel tools by means of rapidly cutting wheels, that the contact between the two should be a line

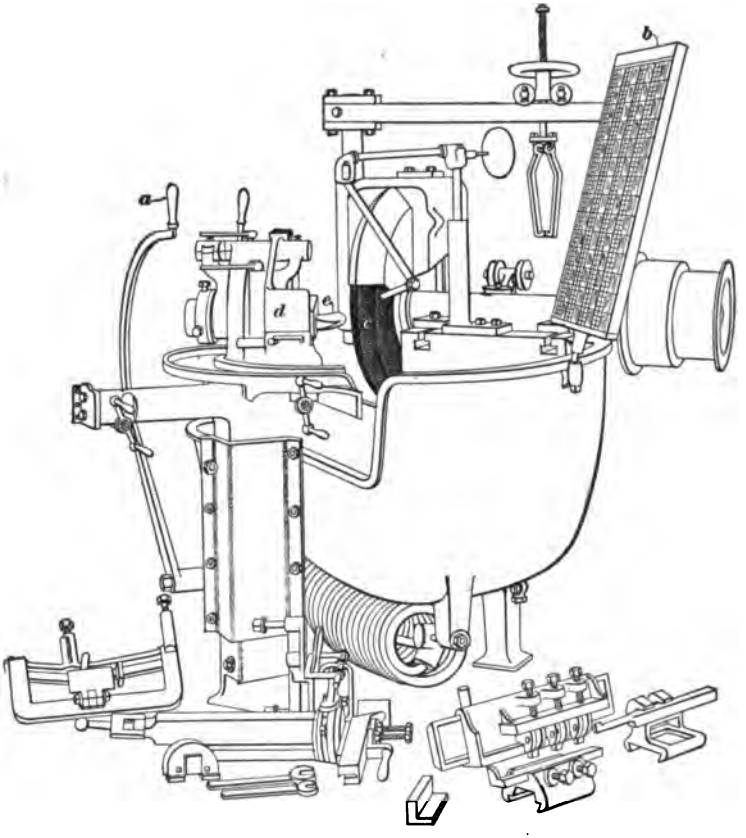


FIG. 13.

and not a surface; hence, if it is desired to grind a plain face of a tool, the wheel must have a cylindrical or conical surface past which the surface to be ground must be moved in a plane. They further state that the plane face of the wheel cannot be used for this purpose because it and the

surface being ground will soon coincide, with the result that no cutting will be done, though considerable heat will be produced.

72. The style of Sellers tool-grinding machine shown in Fig. 13 is provided with a conical wheel *c* and the tools are held in a suitable fixture *d*, one tool being shown at *e*. Another style of machine manufactured by the Sellers Company is arranged to pass the work across the periphery of an ordinary cylindrical emery wheel.

The Sellers machine will not only grind all angles and circles with cone clearance, but it will also, by the use of forms, grind irregularly shaped cutting tools. On this account, it probably has a greater range than any other machine on the market and is remarkably well adapted for shops having a large variety of tools.

73. Gisholt Tool-Grinding Machine. — This machine works on an entirely different principle from the Sellers and is intended only for grinding the regular angles and circles with clearance. For this reason, the Gisholt machine will not serve where an extremely large range of tools is required. As in the Sellers machine, the accuracy of the shape of the tool does not depend on the skill of the workman, but is obtained by the different angles at which the parts and various holders and fixtures are set, these angles being read from a chart. Water is supplied to the wheel on this machine by means of a pump, as in the Sellers.

The main point of difference between the two machines is in the method of presenting the work to the wheel. The Gisholt machine is illustrated in Fig. 14, where it will be seen that the grinding is done on the face of a cup-shaped wheel, the contact between the tool and the wheel being a surface and not a line contact, as the wheel and the surface being ground coincide. In actual practice, the grinding is done rapidly without heating when the right grade and grain of wheel are used and the work is moved past the wheel in the right manner to accomplish the desired results.

In this respect both machines are successful. The reason for the success of this style of machine will be shown under the heading "Selection of Wheels for Tool Grinding." The depth of cut is regulated by means of a cross-feed controlled

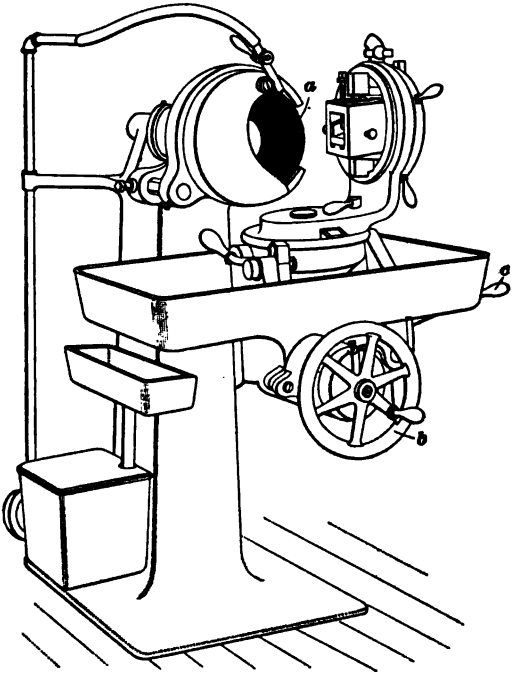


FIG. 14.

by a hand wheel *b* and the tool is carried back and forth across the face of the wheel by means of the lever *c*. The Gisholt machine is very simple and compact, as will be seen by the illustration.

SELECTION OF WHEELS FOR TOOL GRINDING.

74. Grade of Wheel.—In selecting wheels for tool grinding, as has been stated where the subject was under discussion, it should be understood that the result to be

obtained is dependent on many conditions in the wheel aside from the size of grain. The grade of the wheel plays a very important part in the manner in which it does its work. A good illustration in this connection is the case of the Gisholt and Sellers tool-grinding machines, which are designed to use diametrically opposite methods, one using a line contact only, to avoid heating and glazing, the other using a surface contact, and also avoiding heating and glazing.

75. In the case of the Gisholt machine, by using a cup-shaped wheel and grinding against its flat surface, advantage is taken of the possibilities of proper grading as related to the work in hand; for it is true that as the surface in contact becomes greater, the grade of the wheel should become softer, and may be much coarser. In the case of the Sellers machine, by using a line contact on the periphery or conical portion of the wheel, the wheel can be very much harder, which would be an advantage if the operator was grinding tools of irregular form and wished to preserve the shape of the wheel as long as possible. This is true also in many cases where it is desirable to have the wheel remain intact, without change of form on the face. The Gisholt machine is designed to grind flat surfaces, which are passed entirely across the face of the wheel at each stroke of the lever; hence, the face of the wheel is maintained in correct form and the desired result is obtained. At the same time, on the Gisholt machine the wheel may be soft enough and coarse enough to cut freely.

76. The emery wheel for tool grinding should be soft enough to cut freely without requiring too great pressure and without glazing. If only very large tools that present broad surfaces to the wheel are to be ground, the wheel should be softer than if only those tools presenting very small surfaces are to be passed over it. The exact number of emery and the grade of wheel to be used in all cases

cannot be given, because conditions vary so much. It is safe to assume that wheels for this purpose should be so made that the desired surface on the tool will be dependent on the grade of the wheel rather than the grain; that is, the wheels should be quite coarse and very porous, for, as has been stated before, a coarse wheel will produce quite a fine finish if of the right grade and run at the right speed for the work in hand.

77. Some workmen prefer to use a coarse wheel for shaping the tool, and a much finer one, quite soft, for a slight cut to give the desired surface for a cutting edge. In most cases, however, only one wheel is necessary, provided the workmen use an oilstone for the finishing touch.

78. The tendency among users of tool grinders is to select wheels much too hard for the purpose. This is owing to the fact that workmen almost universally fail to appreciate the emery wheel, and do not understand how light a touch is required to grind work very rapidly on a good wheel. A soft wheel, suitable for grinding tools rapidly, will remove a large amount of material instantly with a very light touch of the tool upon it. But as workmen have invariably acquired their experience by using grindstones, they nearly always bear hard upon the emery wheel when grinding tools. This will wear a good wheel very rapidly and cut holes at intervals in the periphery. Thus it is that the purchasers of emery wheels for machinery establishments must select harder wheels than is necessary in order to preserve them.

It is a common complaint among manufacturers of tool grinders that they are obliged to send out wheels that are much harder than the purpose requires. The three wheels that are used quite commonly in tool grinders are the following: Size of grain, No. 30, grade O; size of grain, No. 36, grade N; size of grain, No. 45, grade N; all of them being designated by the Norton Emery Wheel Company's standard.

MACHINE GRINDING.

79. General Consideration.—Machine grinding may be defined as the art of producing very accurate plane, cylindrical, and conical surfaces by an abrading process performed in an automatic grinding machine. Machine grinding differs essentially from hand grinding in that the accuracy of the surfaces produced by it is dependent almost entirely on the accuracy of the machine in which the grinding is done, instead of on the skill of the workman.

In the early attempts that were made to produce very accurate plane, cylindrical, and conical surfaces, a common emery wheel was mounted on a metal planer or on a lathe; in fact, the first forms of grinding machines for cylindrical and conical work were called **grinding lathes.** The early attempts were far from satisfactory, and many persons supposed that the errors frequently found in the work were inherent to the grinding process, and could not be eliminated; in other words, it was supposed that grinding was incapable of producing true work. Painstaking experiments and a careful study of the conditions convinced the pioneer advocates of machine grinding that the faulty work produced was partially due to the selection of wheels illy adapted to the work expected of them, and chiefly to defects inherent to the machinery used. The machinery was gradually improved and the defects were overcome; and with wheels selected to suit the work, the grinding machine of today can be truthfully said to produce round work as accurate as can reasonably be expected and was ever hoped for; in addition to this it was found that some lines of work could be finished to exact size in much less time than by any other method.

80. Classification of Machine-Grinding Operations. — The different grinding operations for which a grinding machine is used may be classified according to the position of the surface operated on as *external grinding* and *internal grinding;* or they may be classified according to the character of the surface as *surface grinding*, which

term is commonly understood to be an abbreviation for "plane surface" grinding, *cylindrical grinding*, and *conical grinding*.

81. External grinding may be defined as a grinding operation performed on the outside surface of a solid; **internal grinding,** as the grinding of the inside surface of a hole. The term **surface grinding** is almost invariably understood to denote the grinding of a plane surface in a machine where the work reciprocates in a straight line, while the term **radial grinding** or **disk grinding** is applied to the grinding of plane surfaces on work rotating about its axis. **Cylindrical grinding,** as implied by the name, denotes the grinding of a cylindrical surface, which may be the inside or the outside surface of a solid. **Conical grinding** is a term that refers to the grinding of a tapering solid of revolution, by **solid of revolution** being meant a solid generated by the revolution of some plane figure about a line as an axis. Thus, a *cylinder* is a solid of revolution generated by revolving a rectangle about one of its sides as an axis; a *right cone* is generated by the revolution of a triangle about one of its sides, etc.

GRINDING SOLIDS OF REVOLUTION.

82. Governing Conditions.—The fundamental principle underlying the grinding of solids of revolution is the application of thousands of cutting points to the surface of the work while it is being slowly revolved about its axis. Each cutting point removes an exceedingly small amount of metal; consequently, the pressure due to the cutting operation is very light. It follows, therefore, that the disturbance of the axes of the work and the wheel is correspondingly small, owing to which fact the resulting solid of revolution is exceedingly true.

If the grinding wheel is traversed along the surface of the revolving solid in a *straight* line parallel to the axis of rotation of the solid, the latter will be ground truly cylindrical;

but if the line of motion of the wheel is at an angle to the axis of rotation of the solid, the latter will be ground conical. It is obvious that the grinding wheel may remain stationary, and that the work may be traversed past it without affecting the result.

In practice, the work or the wheel is made to travel in a straight line by mounting either one on a carriage that slides on straight guiding ways that are so designed as to resist wear, and so protected against injury as to remain true as long as the whole machine can reasonably be expected to last without overhauling and repair. When grinding conical work, it is absolutely necessary that the cutting be done along a line lying in the plane containing the axes of the wheel and work, or, as commonly expressed, the wheel and work must be at the same height above the ways.

83. Classes of Machines Used.—There are two general classes of grinding machines, which are called *plain grinding machines* and *universal grinding machines.* The **plain grinding machines** are designed especially for manufacturing and are made as rigid as possible so as to enable them to do rapid work. All unnecessary adjustments are dispensed with and the machine is made with as few joints as possible. This class of machines is intended for grinding plain cylindrical or slightly conical work, such as spindles, rolls, shafts, etc. In all cases the work runs on dead centers. The **universal grinding machines** are provided with more adjustments, and are adapted for grinding internal or external work (either straight or tapered), cutters, reamers, etc.

CONSTRUCTION OF GRINDING MACHINES.

84. Plain Grinding Machine. — Fig. 15 shows a front and Fig. 16 a rear view of a plain grinding machine, made by the Brown & Sharpe Manufacturing Company, of Providence, Rhode Island. The entire machine is supported

upon a rigid base *a*. The carriage *b* can be moved along the base by the hand wheel *c* or arranged to move back and forth automatically by setting the stops *d* and *e* at the desired places. The table *f* is pivoted upon the carriage *b* so that it can be brought parallel to the line of travel or set at a slight angle for grinding tapers. One end of the carriage *f* is graduated either in degrees or inches per foot, so as to

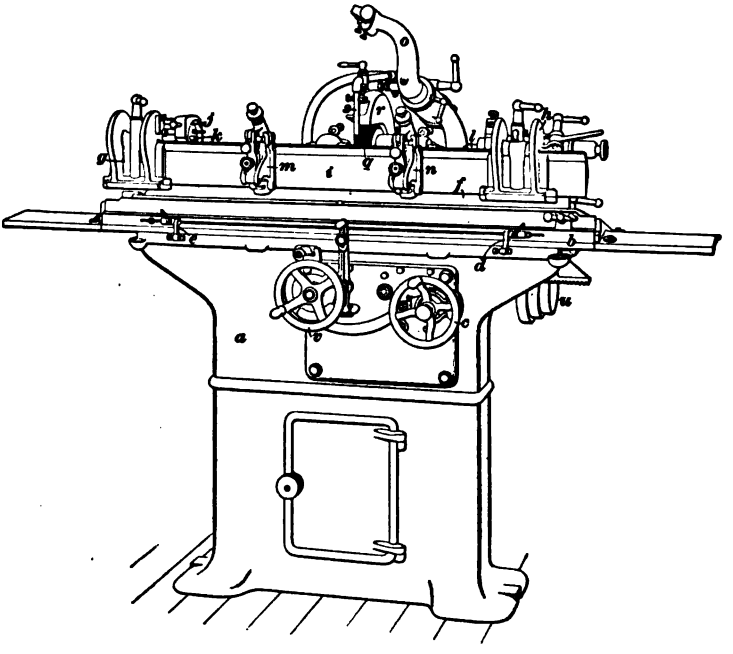


FIG. 15.

assist in setting the work to approximately the right position, the final setting always being made by trial. The headstock *g* and footstock *h* are clamped to the carriage as shown. The main bearing surface for both headstock and footstock is vertical, as shown at *i*. One object of this is to have the main bearing for the headstock and the footstock parallel to the center line of the work and so arranged that differences in the pressure used in clamping the parts, wear, etc. will

have as little influence on the alinement of the work as possible. Another object of this design is to so locate the bearing surfaces that they will be protected from emery dust and water without the use of guards that have to be adjusted for every change in the length of the work being ground.

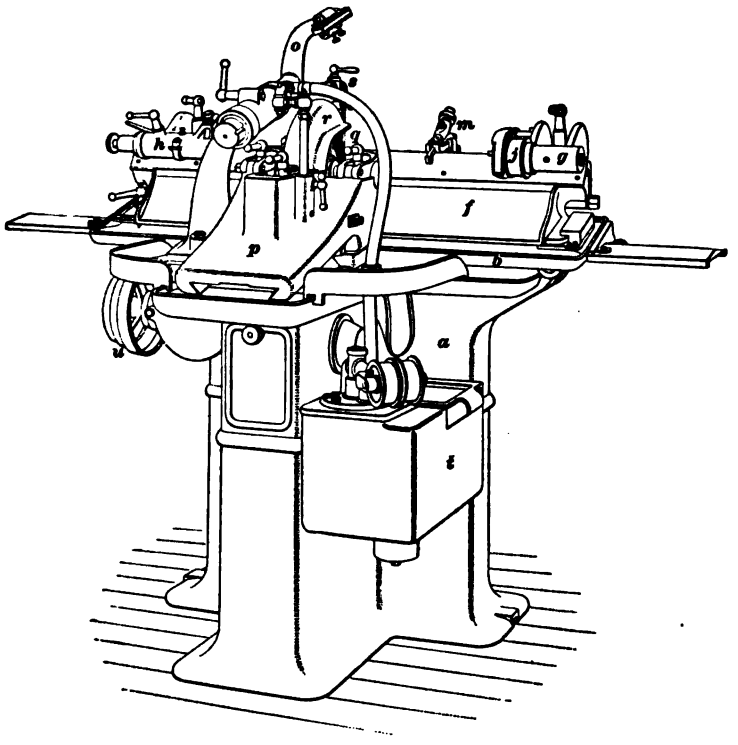


FIG. 16.

Both centers are dead, that is, they do not revolve. The pulley *j* is driven by a belt from an overhead drum that is driven by cone pulleys, so that the speed of the work can be adjusted. The dead centers are shown at *k* and *l*. To assist in supporting the work, fixed rests *m* and *n* may be used or a follower rest may be attached to the arm *o*. The grinding wheel is carried upon the grinding-wheel slide *p*, which is well supported from the floor. The grinding-wheel slide *p*

is set on an incline so that it tends to slide away from the work. This removes all danger of the wheel being

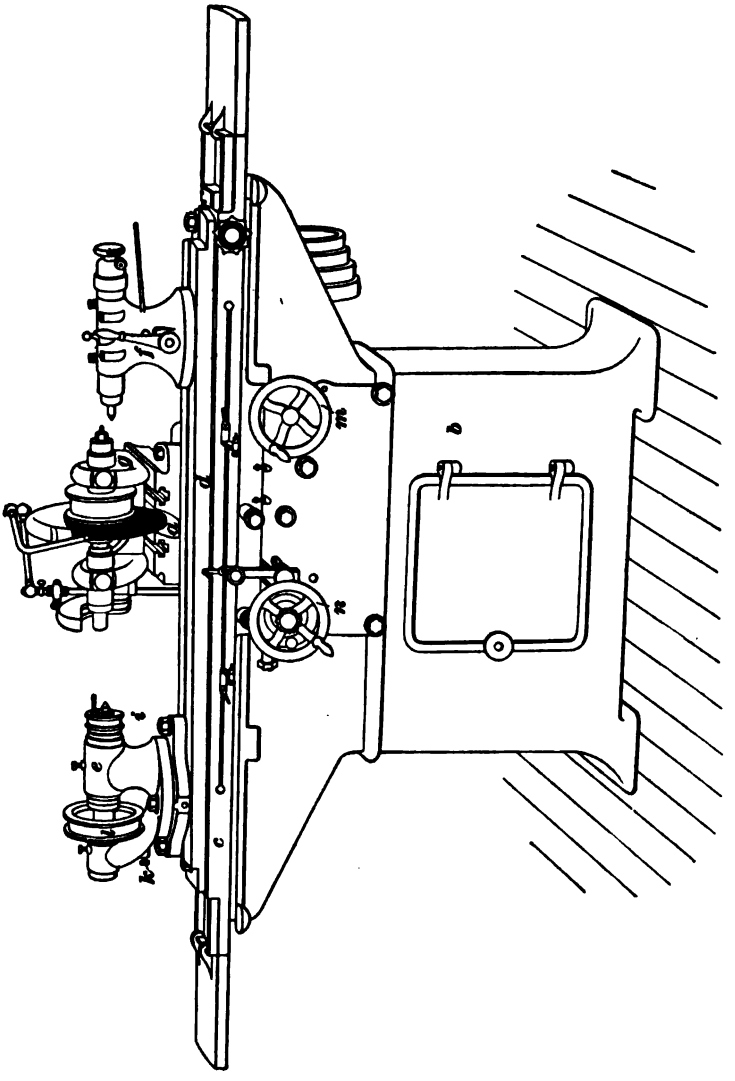


FIG. 17.

moved toward the work on account of any vibration. The emery wheel q is provided with a guard r, and provision is

made for flooding the work with water from the pipe *s*. The water flows back to the tanks *t*, from which it is pumped to the work again. The emery wheel is driven by belts from an overhead drum, and provision is made for varying the speed of the wheel by a series of cone pulleys. The table feed is driven by a belt on the cone pulley *u*.

The grinding wheel and grinding-wheel stand are moved toward or away from the work by means of the hand wheel *v*. Back of the hand wheel *v* is arranged an automatic cross-feed mechanism that will be described later.

As previously stated, both the headstock and tailstock centers are dead. This eliminates errors in the roundness of the work due to want of roundness in the live spindle, and any errors that might be caused by the live center running out of true. Work ground carefully on dead centers can be reversed end for end and will then run so true that even a very sensitive indicator will fail to show any error. This test is so rigid that it is very seldom that work done between centers, where one center is a live one, will pass it satisfactorily.

In the machine described, the grinding-wheel carriage stands still and the work moves past it. In the machines manufactured by the Landis Tool Company, of Waynesboro, Pennsylvania, the table carrying the work stands still and the grinding-wheel carriage moves along the work.

85. Universal Grinding Machine. — A universal grinding machine, as made by the Brown & Sharpe Manufacturing Company, Providence, Rhode Island, is shown in Fig. 17. In this particular design of machine, the emery wheel *a* normally remains stationary during the grinding and the work is traversed past it. The guideways are formed on top of the base *b*, and serve to guide a long carriage *c* to which the table *d* is pivoted. This table carries the headstock *e* and footstock *f*, which can be clamped to it in any position throughout its length. The emery-wheel stand *g* is mounted on a slide that normally is at right angles to the guideways on top of the frame. This stand *g* can be moved

along its slide toward or away from the work by turning the wheel *n*. The slide on which the emery-wheel stand is mounted is pivoted to its base, to which it can be clamped at any angle with the guideways that the construction permits. This allows short conical work having a large included angle to be ground; in that case the table *d* carrying the work will remain stationary while the wheel is traversed past the work.

86. In universal machines the headstock has a live spindle to which a chuck or a face plate may be fitted; this live spindle is driven by a belt from an overhead drum. Provision is made for grinding on dead centers by placing a loose pulley *i* on which a belt can be put, on the end of the live spindle, and providing a suitable arrangement for locking this spindle—in this case, a movable pin *k* that can be inserted into a hole in the pulley *l*. The headstock is placed on a base to which it is pivoted in order to allow the axis of the live spindle to be placed at any angle with the table that the construction of the machine permits. This adjustment permits conical work held in the chuck or face plate to be ground without disturbing the setting of the table or of the slide carrying the emery-wheel fixture. The headstock base, bottom of grinding-wheel stand, and end of the table are all provided with graduations. These graduations are used in setting the different parts of the machine to approximately the desired angle for any work in hand.

The carriage *c* is moved past the emery wheel by turning the hand wheel *m*; it is also provided with a feed that can be automatically stopped at any point within the range of motion of the carriage.

87. The footstock of a grinding machine serves the same purpose as the tailstock of a lathe, but differs considerably from it in its general construction. The footstock spindle of a grinding machine, as a general rule, is provided with some form of a spring that operates it and regulates the pressure with which its center is pressed into the center of the work. Such a regulation of the pressure contributes, in

a large measure, to the accuracy of the work, inasmuch as it prevents springing of the work by an excessive setting up of the footstock center which a careless operator is very apt to do. This spring also maintains a constant pressure on the center, even though there may be considerable wear of the center hole, or the work be lengthened by expansion.

88. Fig. 18 shows the construction of the footstock of the grinding machine made by the Landis Tool Company. A lever *a* is pivoted to the frame of the footstock; it carries a pin *b* at one end that is placed in a hole cut into the spindle *c*. The lower arm of this lever is acted on by a plunger *d* and a helical spring *e*; this spring tends to move the footstock spindle forwards. Obviously, the pressure with which the footstock center presses against the work is that caused by the tension of the spring *e*. The tension

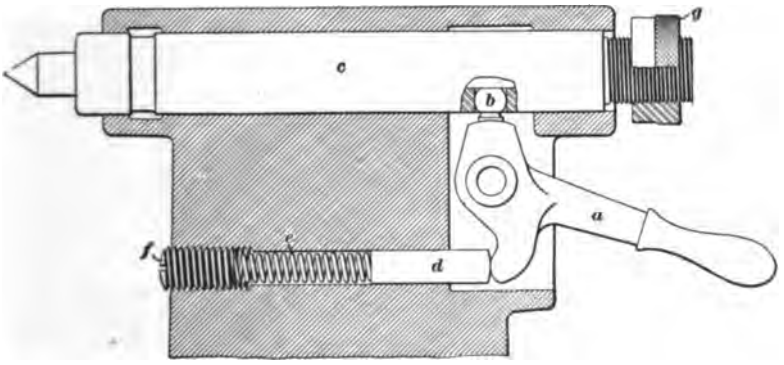
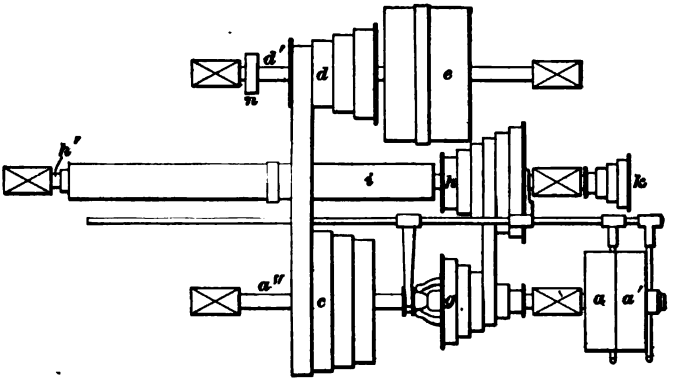
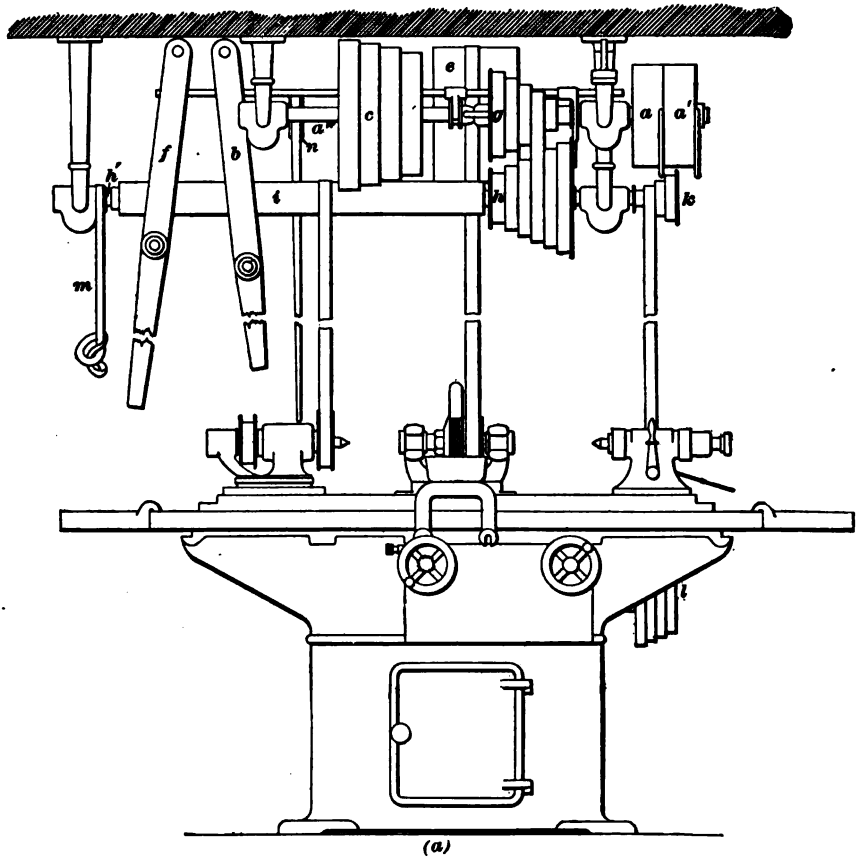


FIG. 18.

of this spring can be regulated by means of the adjusting screw *f*. For very small work, even the lowest tension of the spring may cause enough pressure to bend the work, in which case the pressure may be relieved to any desired extent by screwing the nurled relieving nut *g* against the end of the footstock. If this is done, the operator must use great care not to turn the relieving nut so much as to loosen the work, which can be told by tightly grasping the work and, while shaking it, observing if there is any end play.



(b)



(a)

FIG. 19.

Footstocks are constructed in a number of ways by the different manufacturers of grinding machines; it is believed that all of them, however, contain a provision of some kind for preventing an excessive pressure on the work in the direction of its axis.

89. Overhead Arrangements. — Figs. 19 and 20 show the arrangement of the countershafts for the universal grinding machine illustrated in Fig. 17. Fig. 19 (*a*) is a front view, Fig. 19 (*b*) a plan of the overhead arrangements,

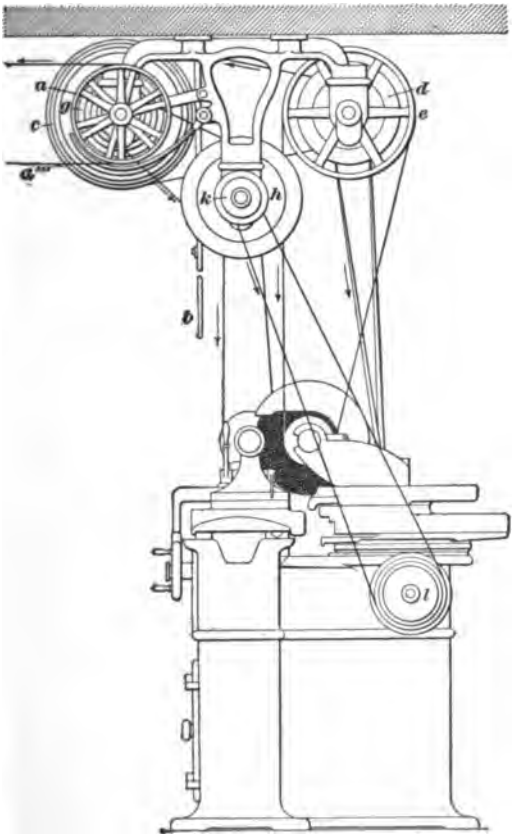


FIG. 20.

and Fig. 20 an end view of the machine. A tight and a loose pulley *a* and *a'* are placed on the countershaft *a''*, which is driven by belting it to a line shaft, and which can be stopped and started by shifting the driving belt *a'''* by means of the shifter *b*. A cone pulley *c* is keyed to the countershaft *a''* and is belted to a cone pulley *d* on the emery-wheel countershaft *d'*, which carries the cylindrical pulley *e* that is belted to and drives the emery-wheel shaft. From this arrangement, it follows that the emery wheel is stopped and started by operating the shifter *b*. A cone pulley *g* is placed on the countershaft *a''*, to which it can be attached by means of a friction clutch operated by the shifter *f*. The cone pulley *g* is belted to a cone pulley *h* on the headstock countershaft *h'*, which carries the long cylindrical drum *i* that is belted to the headstock. Two separate belts are provided for driving the work, one of which is used for grinding on dead centers and the other for rotating the headstock spindle for chuck work and face-plate work. The belt that is not in use, as the belt *m* in this case, is removed from the drum and hung up where it is out of the way. The different feeds are driven from the headstock countershaft *h'* by belting the cone pulley *k* to the feed cone pulley *l*. By tracing out the belting, it will be seen that the work will have a direction of rotation opposite to that of the emery wheel. A rotary force pump is driven by belting it to the pulley *n*.

It is necessary in any grinding machine to so arrange the countershafts that the speeds of the emery wheel and of the work can be changed independently of each other in order that the best speed may be obtained for each. The changes of speed are usually obtained by placing the belts on different steps of the cone pulleys.

90. Automatic Cross-Feed.—The best grinding machines are now fitted with automatic cross-feeds. This feed differs essentially from that of a lathe, however, in that its purpose is *not* a constant movement of the grinding wheel in a direction crossing the axis of the

work. Rather, its purpose is to automatically advance the grinding wheel a predetermined distance toward the axis of the work as soon as the wheel or the work has come to the end of its longitudinal traverse; the automatic cross-feed is intended to repeat this operation a predetermined number of times and then automatically stop the advance of the wheel toward the axis of the work. In other words, the automatic cross-feed relieves the operator from the necessity of feeding the grinding wheel forwards after each cut, and, furthermore, when correctly set will grind the work to the desired diameter and then automatically stop grinding, thus preventing the grinding of work too small.

91. Automatic cross-feeds are constructed in various ways, but the principle upon which they work can be illustrated by a description of the one illustrated in Fig. 21, which shows the details of the cross-feed used upon the machine shown in Fig. 17. The length of the table stroke is controlled by the stops *i* and *j*, which operate the lever *g*, thus reversing the table. The cross-feed is operated by the mechanism attached to the lower end of this lever *g*. When the hand wheel *h*, a portion of which is broken away in the illustration to show the details, is rotated in the direction of the arrow, the grinding wheel is moved toward the work, and when rotated in the opposite direction, it is moved away from the work. The ratchet wheel *a* is attached permanently to the hand wheel and contains a slot *m* carrying a loose ring. To this ring is attached a block *l*, the block being pivoted to the ring at *n* and being provided with a latch *p*, which is so arranged that when it is pressed against the stop shown on its right, it will move the ratchet one tooth. The latch *p* can be disengaged from the ratchet by raising the left-hand end of the block *l*, provision for this being made by the slot which surrounds the screw, as shown in the illustration. The block *l* carries a shield *r*, which, by passing under the point of the pawl *b*, can prevent its engaging the ratchet wheel. The ratchet wheel is operated

by means of the pawl *b*, which is connected to the lever *c*, the latter being pivoted at *d* and being operated by an inclined block that engages the lower end of the lever *g*. The amount that this block engages the lever *g* is controlled by

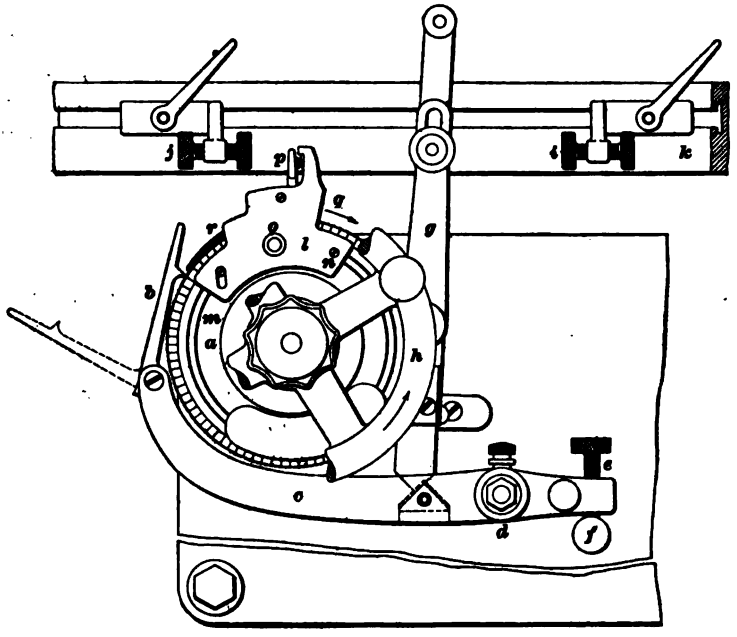


FIG. 21.

the screw *e* and stop *f*. By this means the lever *c* can be so adjusted that the pawl *b* will move the wheel through one or more teeth at each end of the stroke, that is, whenever the lower end of *g* is thrown across the V-shaped stop upon *c*.

92. Having described the uses of the various parts, the operation of adjusting the cross-feed may be described as follows: The stroke of the table *k* is adjusted by means of the stops *i* and *j*, after which the hand wheel *h* is carefully turned in the direction of the arrow until the wheel nearly or just touches the work. The stroke of the table is then stopped, and without changing the hand wheel *h* the screw *o*

is loosened and the block *l* raised until the latch *p* is out of contact with the teeth of the ratchet. The block *l* is held in this position with the right hand, while with the left hand the pawl *b* is swung into the notches of the ratchet, after which the block *l* is moved around until the point of the throw-out shield *r* is just past the tooth occupied by the pawl *b*, the pawl being lifted out of the way to allow the shield to pass. The block *l* is then let down so as to bring the latch *p* into contact with the ratchet once more, and the thumbscrew *o* tightened. The pawl *b* is then thrown back against the shield *r*, which will prevent its coming in contact with the ratchet. The table stroke is next started, and if the pawl *b* does not engage the teeth of the ratchet when the lever *g* depresses the lever *c*, it may be made do so by pressing one or more times upon the latch *p*. This is done by placing the thumb against the latch and the forefinger against the projection extending up from the block *l*. The pawl *b* will then turn the ratchet and hand wheel, thus feeding the emery wheel forwards until it cuts the work, the pawl once more coming to rest upon the shield *r*. Allow the machine to run until the cut is practically ended, stopping the table at the footstock end of the stroke with the shifter and overhead brake. Now measure the work, ascertaining the quarter-thousandths to be taken off to bring it to the correct size. Press the latch *p* once for each quarter-thousandth of an inch; thus, for .003 inch, press the latch 12 times, start the table, and the pawl will move the ratchet until the shield *r* prevents the pawl *b* catching another tooth Allow the wheel to pass over the work until it shows the same cut as when the measurement was taken and stop the table at the footstock end, as before. If a suitable wheel is used, the diameter will show a reduction of .003 inch. If the work does not show this reduction, the latch *p* is pressed once for every quarter-thousandth further reduction necessary, and the machine started up once more, as before. When the work is the right size, the pawl *b* is thrown out and, without changing the position of the block *l*, the hand wheel *h* is turned in a direction opposite to

that of the arrow for about one turn. This will remove the emery wheel from the work. When the next piece of work is in place and the table stroke started, the hand wheel is turned in the direction of the arrow until the emery wheel just cuts, then the pawl *b* is thrown into the notches and the machine allowed to continue its work until the shield *r* has again stopped the feed by disengaging the pawl *b* from the ratchet wheel. When the emery wheel shows the same cut that it did when finishing the first piece, the machine is stopped as before and the work measured. If the work is large, the latch *p* is pressed as many times as the work is quarter-thousandths large and the grinding continued until the right dimension is obtained. After the wear of the wheel has been determined, it is possible to press the latch *p* the proper number of times before beginning the cut on each new piece and thus finish the piece to the exact size at one operation.

93. When setting the automatic cross-feed, it must be remembered that the depth of each cut is dependent on the number of teeth the ratchet is moved at the end of each stroke. The number of teeth that the ratchet wheel is moved at each stroke is controlled by means of the adjusting screw *e*, which controls the movement of the lever *c* and the pawl *b*. The throw-out shield *r*, by its position, simply determines the total depth of the successive cuts, that is, the total distance that the grinding wheel is moved toward the work.

94. The diameter of the work produced by the automatic cross-feed should be measured after the wheel has stopped cutting, or when the amount of sparks given off shows that it is cutting at the same rate that it did when the previous piece was measured. The reason for this is that the grinding wheel will continue to reduce the diameter slowly for some time after the feed has been stopped.

95. The cross-slide on which the wheel of a grinding machine is mounted must move quite freely in order that

it may be moved an amount as small as .000125 inch. In order to keep the wheel slide in good condition, it should be oiled with good oil each day and moved throughout its entire length during the operation, so as to insure thorough lubrication. If the wheel slide is allowed to remain stationary for some time without lubrication, it may be necessary to clean the parts before they will work freely again, though usually the working of a good quality of oil through the oil holes and the moving of the parts throughout their entire travel several times will put the working parts in good condition.

96. The automatic cross-feed is a valuable addition to the grinding machine, on account of the fact that it not only enables the operator to attend to other details while the piece is grinding, thus saving much time, but by uniform movement it maintains the proper condition of the emery wheel and increases its sizing power. This latter feature is one that has received very little attention in the past, but is of great importance if it is desired to finish duplicate pieces.

GRINDING.

(PART 2.)

GRINDING SOLIDS OF REVOLUTION.

ADVANTAGES OF GRINDING.

1. When grinding machines were first designed, they were used almost entirely for hardened work, the prevailing idea being that grinding was a refined perfecting process suitable only for the finishing of hardened work that required a great degree of accuracy. This idea still prevails in many quarters, but it is incorrect, since experience has shown that whenever a suitable grinding machine is intelligently used the accuracy that may be attained when soft work is finished by grinding is accompanied by a reduction in the cost of the work over that which has been accomplished by other processes. Thus, many kinds of cylindrical work, such as shafts, spindles, studs, arbors, etc. that are made of soft steel may be turned to nearly the finished size, and then by careful filing, followed by an intelligent application of emery cloth, brought to the correct size. By using a grinding machine, however, most of the cost of the files and emery cloth is eliminated from the charges against the work; furthermore, the quantity of metal left for finishing can be removed much faster by grinding than by filing or turning in the lathe, at least on work that is within the capacity of the grinding machine.

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2. It has been shown in actual practice that a grinding machine fitted with a 12-inch grinding wheel, which is a common size, will reduce a cylindrical piece of steel from .005 inch to .012 inch in diameter in less time than would be consumed in reducing the diameter an equal amount in a lathe. With especially heavy and powerful grinding machines, a greater amount than that named above can be removed.

3. While the grinding machine may in the future be developed sufficiently to adapt it for roughing out work, it is not developed enough for that at present, and the work must come to the grinding machine roughed out to within .005 inch to $\frac{1}{16}$ inch of the finished size in order that the machine may not work at a serious disadvantage. When the amount of metal to be removed is within the limits stated, grinding is not only an economical, but is also a very desirable, finishing process on account of the great accuracy attainable.

4. An emery wheel having a diameter of 18 inches and a face $\frac{3}{4}$ inch wide, when running at its ordinary speed, presents approximately 2,500,000 cutting points to the work in 1 minute, and a wheel of the same diameter, but having a face $1\frac{1}{2}$ inches wide, presents about 5,000,000 cutting points to the work in the same period of time. Each of these cutting points removes a very small amount of metal; but when the aggregate amount is considered it is comparatively large. Furthermore, in modern grinding machines the cutting points pass over from 1 to 4 square feet of surface per minute. The statements just made will serve to explain why, within reasonable limits, the grinding machine can remove metal faster than the lathe, with its single cutting point.

5. The purposes and advantages of machine grinding may be briefly summed up as follows: In the first place, it is economical to finish work to size by grinding; in the second place, the accuracy attainable is very great. The first advantage named is, today, the most important one,

and fits the grinding machine for manufacturing purposes on work within its range and capacity; accuracy is given the second place, because the accuracy readily attainable by grinding is far beyond that which is necessary on most duplicate work.

SELECTION AND USE OF GRINDING WHEEL.

SELECTION OF WHEEL.

6. Grade.—In order that the grinding wheel used in machine grinding may cut freely, that is, with little or no pressure, it is desirable that the wheel be "self-sharpening." A *self-sharpening grinding wheel* is one in which the dulled particles of the abrasive material break away readily during the grinding operation, and the ease with which these particles become detached, or the resistance that they offer to breaking out, determines the **grade** of the wheel. Thus, if the particles break away readily, the wheel is said to be **soft,** while one that offers considerable resistance to the detaching of the dulled particles is called **hard.** From this explanation it should be plain that the terms "soft" and "hard," when applied to a grinding wheel, do *not* refer to the relative hardness of the abrasive material, but merely to the facility with which the dulled particles become detached.

7. Causes of Glazing.—It is evident that the longer the dulled particles are retained, the duller will they become, and that, consequently, more pressure will be required to make them cut. Undue dulling of the particles is also caused by an excessive speed. The dulling of the particles manifests itself by the glazed appearance of the cutting surface of the grinding wheel, and by considering the causes of this glazing we would be justified in drawing the conclusion that *a wheel that glazes rapidly is either too hard for the work it is performing or is run too fast.* A wheel that

requires much pressure to make it cut will not produce the best results, no matter how rigid the machine in which it is used may be, for the reason that the pressure of the grinding will disturb both the axis of the wheel and the axis of the work.

8. Influence of Hardness of Material.—Since different materials vary in their hardness, the rate at which they will dull the grinding wheel also varies. Naturally, the harder material will dull the abrasive substance incorporated in the wheel more rapidly than will the softer material; from this we may draw the conclusion that *the harder the material is, the softer should be the grade of the grinding wheel.* Because of this fact, it should be remembered, when considering the working of different grades of steel, that since high-carbon steels are harder than steels containing only a low percentage of carbon, they require a softer grinding wheel, while low-carbon steels can be advantageously ground with a wheel that is harder and denser.

9. The different high-carbon steels of the variety known among shopmen as "tool steel" vary but little in their relative hardness, and, consequently, a wheel suitable for one kind of such high-carbon steel will work satisfactorily on most other grades of such steel. Steel that is low in carbon, commonly called "machinery steel" by shopmen, is quite soft, and experience has shown that it can probably be ground best by using a **combination wheel,** which is a wheel in which several sizes of grains are incorporated. Thus, a wheel in which No. 36, 46, 60, 80, and 100 emery is incorporated is a combination wheel that is suitable for some kinds of work.

10. Influence of Vibration of Work.—The steadiness of the revolving work while it is being ground must be considered in deciding on the grade of the wheel that is to be used. If the work vibrates somewhat, the wheel should be harder than if the same work was perfectly free from vibration. The reason for using a harder wheel is that the vibration of the work has the same effect on the cutting

surface of the wheel as a succession of hammer-blows, which would break the particles of the abrasive material away too rapidly if a soft wheel were used.

DIRECTIONS FOR SELECTING WHEELS.

11. In order to aid the grinding-machine operator in selecting a suitable wheel, the Landis Tool Company publish the directions given below, where the grade of the wheel is given in accordance with the standard of the Norton Emery Wheel Company.

12. Wheels for External Grinding.—For grinding hardened steel, in roughing it down to nearly the desired size, use a No. 60 emery wheel, grades K to M; for finishing hardened steel, according to the degree of finish desired, use a No. 60, 80, 100, 120, or 150 emery wheel of the grades I to M. For roughing soft steel down to nearly the finished size, use wheels from No. 46 to No. 60 of the grades M, N, or O; and for finishing soft steel, use, according to the degree of finish desired, wheels from No. 60 to No. 180 of the grades L or M. For roughing cast iron down to nearly the finished size, use wheels from No. 46 to No. 60, and of the grades G to K; for finishing cast iron, use wheels from No. 60 to No. 80 of the grades K to M. To finish brass or bronze, use a wheel from No. 60 to No. 120, according to the degree of finish desired, and of the grades F to K.

13. Wheels for Internal Grinding.—For roughing out soft or hardened steel, use a wheel from No. 46 to No. 60 of the grades G to K, and for finishing soft or hardened steel, use a wheel from No. 60 to No. 100 of the grades E to F. For roughing out brass or bronze, use the same wheels as for roughing out steel; for finishing brass or bronze, use, according to the degree of finish desired, a wheel from No. 80 to flour emery of the grades E to F.

14. The directions here given should be considered merely as an aid in selecting a wheel. The results must be

observed and the wheel then changed to suit, if found unsatisfactory. The Brown & Sharpe Manufacturing Company recommend that for internal grinding only corundum wheels be used.

15. Shapes of Wheels.—Emery wheels and similar grinding wheels are made in various shapes by the different manufacturers; some of the shapes most commonly used in

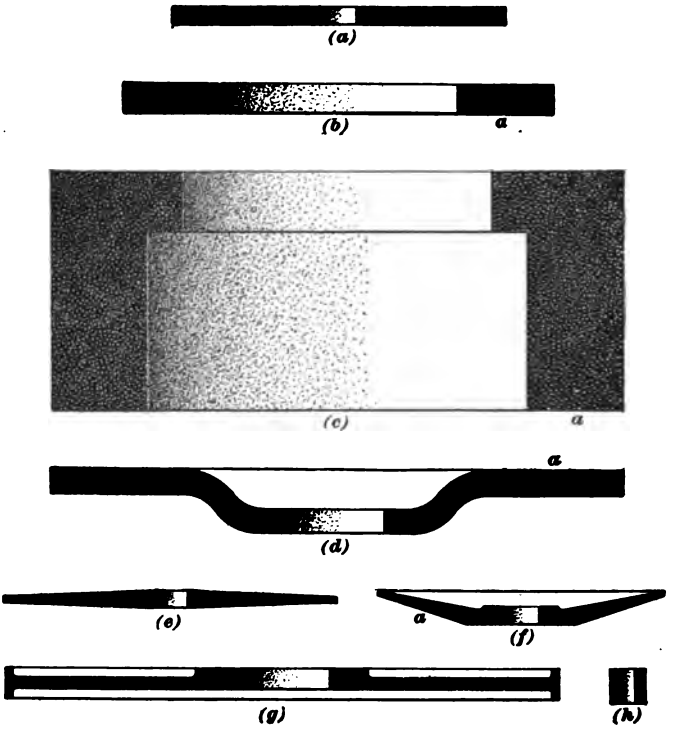


FIG. 1.

machine grinding are given in Fig. 1. Wheels having the shape of a flat circular disk with a small central hole, as the one shown in Fig. 1 (*a*), are used for external grinding, the cutting being done by the periphery. The wheels most commonly used on universal grinding machines have large

central holes, as shown in Fig. 1 (*b*). Such wheels are mounted on special arbors or upon bushings on an ordinary arbor. Cupped wheels like the one shown in Fig. 1 (*c*) are usually mounted directly upon the spindle and are used for surface grinding, the face *a* being used for this purpose. Sometimes these wheels are made without the shoulder for attaching them to a spindle, in which case they are simply plain cylinders. Such wheels are mounted in a chuck and used for surface grinding. If the wheel shown in Fig. 1 (*b*) had a face several inches wide, it could be used for surface grinding by mounting it in a chuck, the work being done upon the face *a*. A wheel that has the shape shown in Fig. 1 (*d*) is used for grinding close to the shoulder of work that has a very large flat shoulder; the shape of the wheel permits this to be done since it allows the face of the nut that fastens the wheel to the spindle to come below the face *a* of the wheel. The grinding is done by the periphery of the wheel.

16. A narrow conical wheel, like the one shown in Fig. 1 (*e*), is much used for grinding the clearance of reamers, milling cutters, and similar cutting tools in cutter-grinding machines, in which case the wheel is used dry. The narrow face of this wheel will not grind as fast as a wide-faced wheel, neither will it generate as much heat, which fact makes the narrow-faced wheel more suitable for dry cutter grinding than the wide-faced wheel. A beveled wheel of the shape shown in Fig. 1 (*f*) is much used for sharpening the teeth of narrow formed cutters, as, for instance, gear-cutters; the grinding is usually done by the inside face, the conical surface *a* just clearing the back of the next tooth of the cutter. A recessed wheel of the form shown in Fig. 1 (*g*) is used for grinding a square shoulder on cylindrical work, and like the cupped wheel illustrated in Fig. 1 (*c*), it can be used for surface grinding on light work, such as the measuring surfaces of caliper gauges. For internal grinding of small holes, the wheel may assume the shape shown in Fig. 1 (*h*).

17. As far as the shape of the face of the wheel is concerned, the wheel may be turned with a diamond tool to almost any form desired. For regular work in automatic grinding machines, the cutting face of the wheel is usually either a flat surface, as the side of a wheel, or the surface of a cylinder. These two elementary forms are modified to suit special conditions.

SPEEDS AND FEEDS.

18. Surface Speed of Grinding Wheel and Work. The relation between the surface speeds of the grinding wheel and the work will become clear when we consider as a parallel case the relation between the cutting speed of a milling cutter and the feed of the work in a milling machine; since the act of revolving a piece of work in the grinding machine may be likened to the feed of the work in a milling machine, while the cutting points of a grinding wheel may be likened to the cutting edges of a milling cutter.

19. Suppose that a milling cutter is cutting steel, running at a surface speed suitable for a proper maintenance of the cutting edges; there is then one particular feed of the work at which the cutter will work at its best, and if this rate of feed is increased too much, the teeth of the cutter will be broken off. If the milling cutter is speeded too high, the heat generated by the cutting operation will be sufficient to draw the temper in the cutting edges, which are rapidly dulled in consequence of the excessive speed. Also, if the milling cutter is speeded to the proper cutting speed while the work is fed so slowly that the cutter may be said only to rub the work instead of taking a distinct chip, its cutting edges will be rapidly dulled.

20. Considering now a grinding wheel, if we revolve it at the proper speed but revolve the work too fast, there will be too much stress upon the cutting points (the particles of the abrasive material), which, consequently, will break away, thereby rapidly changing the diameter of the wheel. This change in diameter will produce a corresponding change

in the diameter of the work. In other words, too great a surface speed of the work reduces the diameter of the wheel too rapidly and thus destroys its sizing power.

21. When the grinding wheel is run at too high a speed while the work is revolving at a proper speed, the wheel will rapidly dull and become glazed on account of the heat generated. In the case of a grinding wheel running at the proper surface speed, but on work that is revolving too slowly, the wheel will dull rapidly because there is not enough stress on the cutting points to break them, and this dulling will be intensified by the heat that is generated. When the wheel is run at too low a speed, the speed of grinding is proportionately reduced.

22. Practice has shown that for the grinding wheel a surface speed of 6,000 feet per minute is suitable for hardened steel, cast iron, and chilled iron. For grinding soft steel and other metals except those named, the grinding wheel may be given a surface speed of 7,000 feet per minute. The average surface speed of the work is 100 feet per minute, but it may be considerably higher under certain conditions. For instance, suppose the operator to have a wheel in his machine that was suitable for a job just finished, but which is a little too hard for the new work. In such a case, provided of course that the difference in the grade of the required wheel and the available wheel is not too great, the operator may, by slowing down the speed of the wheel and increasing the speed of the work, get satisfactory results.

23. Chatter Marks. — It often occurs in machine grinding that the ground surface has a peculiar wavy appearance to which operators have given the name of **chatter marks.** These marks may be due to a number of different causes, each one of which may act by itself or in conjunction with the others. The most common causes are improperly supported work, looseness of the grinding-wheel spindle in its bearings, and too hard a wheel. Work lacking inherent stiffness should be supported by proper steady

rests; a loose grinding-wheel spindle can be cured by tightening the bearings; but a wheel that is too hard is best replaced by a softer one. As a makeshift it is often possible to make a hard wheel cut without chattering by turning down the wheel with a diamond, and so narrowing its cutting surface. If this is done, it must be remembered that the amount of work that can be done per minute is lessened, since the amount of material removed by a grinding wheel depends directly on the width of the cutting surface in contact with the work. From this it follows that a reduction in the width of the wheel calls for a finer feed.

24. In some cases, the ground surface may have a mottled appearance, or it may be full of ridges that are either parallel to the axis of the work or wind around it like a thread. This appearance of the work is due to any one of a number of causes, among which may be mentioned vibration of the piece, too slow or too fast speeds for the wheel or work, centers not in good contact, inequalities in the stock, work not suitably supported, or a glazed wheel. When a wheel is glazed, it is probable that there are one or more spots on the circumference of the wheel that are sharper than the remainder; these sharp spots may be likened to the cutting edges of a milling cutter that has but few teeth. In consequence, the cutting is intermittent, and the ridges, which may be likened to the revolution marks of a milling cutter, appear. The best remedy is to select a softer wheel.

25. Truing the Wheel.—It is essential to good grinding that the grinding wheel should run very true and bear

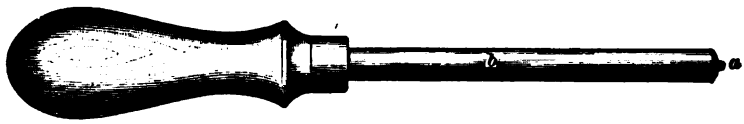


FIG. 2.

evenly against the work over its entire cutting surface. A diamond tool is absolutely necessary for truing the wheel,

a good form of which tool is shown in Fig. 2. A small diamond *a* is set centrally into the end of a cylindrical rod or shank *b*, to the other end of which is fitted a suitable wooden handle. Sometimes the diamond is set into a rectangular shank, but if this is done, the diamond can be used in only two or four different positions, and hence the round shank is better for general work.

26. There are various ways of applying the diamond-pointed tool to the wheel. Some machines have devices for holding it, but in practice a grinding-machine operator will usually find it more convenient to do the truing by hand, resting the tool on the footstock center and steadying it by bearing against the end of the work, the latter being stationary. While holding the diamond tool steadily in place, the revolving wheel is moved back and forth past the tool, or vice versa; with a little care, it is quite easy thus to produce a true running wheel that has a cutting surface parallel to the line of motion.

27. Beginners are very likely to overlook the necessity of having a wheel run exactly true and having it cut evenly throughout its width; if this is not the case, the wheel is very liable to make a cut so rough that a beginner will misjudge the wheel and pronounce it too coarse and unsuitable for the work, while in reality the same wheel if properly trued would produce an even and smooth surface. If the wheel does not cut over its entire surface, i. e., if the cutting surface is not parallel to the line of motion, it is not possible to feed at the proper rate without showing distinct feed-marks in the form of spiral lines running around the work. The beginner is likely to attribute these feed-marks to too rapid a feed, when in reality they are due to an improperly trued wheel.

INFLUENCE OF TEMPERATURE.

28. Local Heating and Its Prevention. — When grinding solids of revolution in a grinding machine, the work and the wheel are often flooded with water for the

purpose of carrying away the heat generated by the grinding operation. The work is thus kept at a temperature that is uniform enough to prevent a sensible change in the outline of the work.

29. Any one who has done lathe work knows how hot the work becomes under the influence of the cutting operation; and as in grinding, the cutting is done much more rapidly, and, besides, by a great number of cutting points, the local heating of the work at the place where the grinding is being done is more pronounced. Now, even if the rise in temperature is so slight that the bare hand cannot detect it, a local heating of any piece of work will cause a change in the outline of the piece that is greater than is ordinarily supposed. This change in outline becomes very apparent in a grinding machine, in which under proper conditions a grinding wheel is capable of showing an error as small as .000005 inch, the error becoming apparent by the increase or diminution of the sparks coming from the wheel when cutting.

30. The influence of local heating on the quality of the work is well shown when an attempt is made to grind dry a slender cylindrical piece of steel between centers. As the grinding passes back and forth over the work, the operator will notice that sometimes the wheel is grinding more on one side of the work than on the other, and at other times, it will grind on one side only. Passing over the work again, the wheel may cut on the opposite side, then it may cut at right angles to where it last cut, and so on. No matter how long the grinding continues, the cylinder will not become round.

31. The following considerations explain why the work does not become round. Suppose we hold a round bar or piece of steel in our hands and press a point about midway between its ends against an emery wheel. Then, the grinding will cause a local heating at the point in contact with the wheel, and, consequently, the side of the bar that is toward the wheel will elongate, thus causing the ends of the

bar to curve away from the wheel. Now assume that the bar of steel is placed between centers in a grinding machine, and that the wheel is again cutting midway between the ends. Then, as in the previous case, the side of the bar in contact with the grinding wheel will elongate, but as the ends cannot curve away from the wheel, since they are held by the centers, the middle of the bar will curve *toward* the wheel. The fact that the bar may be revolving does not alter the case, since the point where the grinding is taking place is always hotter than the opposite side of the bar. If the wheel is passed back and fort'i over the bar, it is easily seen that the side of the bar where the sparks show will be constantly elongated, and if the piece being ground is entirely free from internal stresses and of absolutely uniform density, it will be ground round, but smallest at the middle. Unfortunately the ideal condition of a piece of work free from internal stresses and of uniform density does not occur in practice; and, in consequence, the elongation of the bar will not be uniform throughout each revolution. Hence the bar will bend a varying amount toward the wheel, and as this is still further varied by the additional heat due to the increased depth of cut, owing to greater elongation at certain points, the result is a bar that is neither round nor straight.

32. The remedy for the troubles due to change of temperature is simple: flood the work with sufficient water to maintain a uniform temperature and use a suitable wheel.

33. Noting the Sparks. — In regard to the sparks being an indication of the grinding, it may be interesting to know that the amount of metal that is removed when sparks are just visible has been ascertained by experiment. A hardened-steel plug gauge about 1 inch in diameter was placed between the centers of a grinding machine and was carefully ground to run true, allowing it to pass back and forth past the wheel until all sparks ceased. Its size was then noted by careful measurement in a standard measuring machine and it was again placed in the machine. The

grinding wheel was now very carefully moved toward the work until sparks just became visible and was then passed back and forth past the wheel until all sparks ceased. By carefully measuring the work again, it was found that the piece had been reduced .00001 inch in diameter, which showed that the depth of the cut was only .000005 inch. This experiment showed that the grinding wheel when used in a good machine is one of the most sensitive indicators of error.

34. When grinding work, the operator can judge the accuracy with which it is being ground by noting the increase or decrease in the volume of the sparks during the revolution of the work, and an experienced operator can closely tell the amount of error from the relation between the depth of cut and the volume of sparks. This relation can only be studied in actual grinding by noting the volume of sparks emanating from a grinding wheel for a given movement of the wheel slide, as indicated by the dial of the adjusting screw. Since the increase or decrease in the volume of the sparks is an indication of error, it follows that an operator having a knowledge of the amount of error thus indicated may eliminate or reduce many errors by making proper adjustments.

GRADUATIONS.

35. Purpose of Graduations.—The success of the grinding machine in grinding solids of revolution accurately to a predetermined shape, as, for instance, true cylinders or frustums of cones, depends largely on the provision of suitable means for adjusting the line of motion of the grinding wheel or the table in relation to the axis of rotation of the work. These provisions are amply made in the better class of grinding machines that are built today.

36. In order to aid the operator in setting the machine to grind cylindrical or tapering work, all modern grinding machines have one end of the table, which, as previously explained, can be swung around in a horizontal plane,

graduated either to degrees or to read to tapers in inches per foot. These graduations are intended to assist the operator in setting the table *approximately* to the correct position; it is to be distinctly understood that for exact grinding, the means of sensitive adjustment with which the table is provided are to be used after it has been determined by *trial* where the ground work differs from the desired shape.

37. Final Adjustment.—When setting the machine, the operator should set the table by the graduations as nearly as can be judged by eye. It is entirely unnecessary to use a magnifying glass for this purpose. The rough work is now placed in the machine and, by measurement, it is determined which end, if either, is the larger. A very light cut is now taken, observing if the cut is heavier at the larger end, which obviously should be the case. If this is not the case, the table is carefully adjusted until the cut shows heavier at the larger end, which is indicated by the sparks. The work is now ground evenly and is then measured, but if one end is too large, the table is adjusted once more; this cycle of operations is repeated until the table is correctly set.

38. The main reason why the graduations cannot and should not be relied on when accurate work is desired is *not* that the graduations are incorrect, but that any changes of temperature of the machine will affect the relative position of the various parts; any error due to this cause will be doubled in the work. Another reason is the unequal wear of the centers that is liable to occur with constant use, the centers wearing out of line; any error in alinement due to this cause will also be doubled. Thus, if one center is .00025 inch out of line in one direction and the other center is the same amount out of line in an opposite direction, the total error in alinement is .0005 inch, and the error of the work will be .001 inch. A slight amount of dirt or oil in the holes in which the centers are placed will cause a corresponding error in alinement.

39. Adjustment of Headstock.—The headstock of a universal grinding machine is generally arranged so that

it can be swiveled; graduations on its base indicate approximately the angle at which the spindle is set to the line of motion; provided, however, that the table itself is set at zero. When grinding work between centers, it is essential to set the headstock to zero; otherwise the graduations on the end of the table will not show the angle between the line of motion and a line joining the centers. When work that is attached to the headstock spindle is ground, the latter is set roughly by the graduations of the headstock, but the final adjustment is gotten by setting the table over.

40. The adjustment of the table is so simple in all grinding machines that in case the work shows any error due to alinement, the operator finds it more convenient to cure the error by shifting the table than to look for the cause of the error in alinement.

DRIVING WORK BETWEEN CENTERS.

41. Work ground between centers is driven, as in lathe work, by a dog. The dog used should be as light as possible, especially for slender work, and should be well balanced in order that the centrifugal force due to an unbalanced dog may not bend the work during grinding and thus cause poor results. Most grinding machines have a pair of pins set into the face plate, so that a straight-tailed dog having two tails can be used, which is less liable to produce a bending stress on the work at high speeds than the ordinary bent-tailed dog. Owing to the fact that the work revolves at a slow speed, it is not often that the centrifugal force due to an unbalanced dog has to be taken into account.

EXTERNAL GRINDING.

METHODS OF GRINDING.

42. Introduction.—A good idea of the kind of work that can be done in a grinding machine can be obtained by an examination of the several examples of **external grinding** that are given below. These examples will serve to

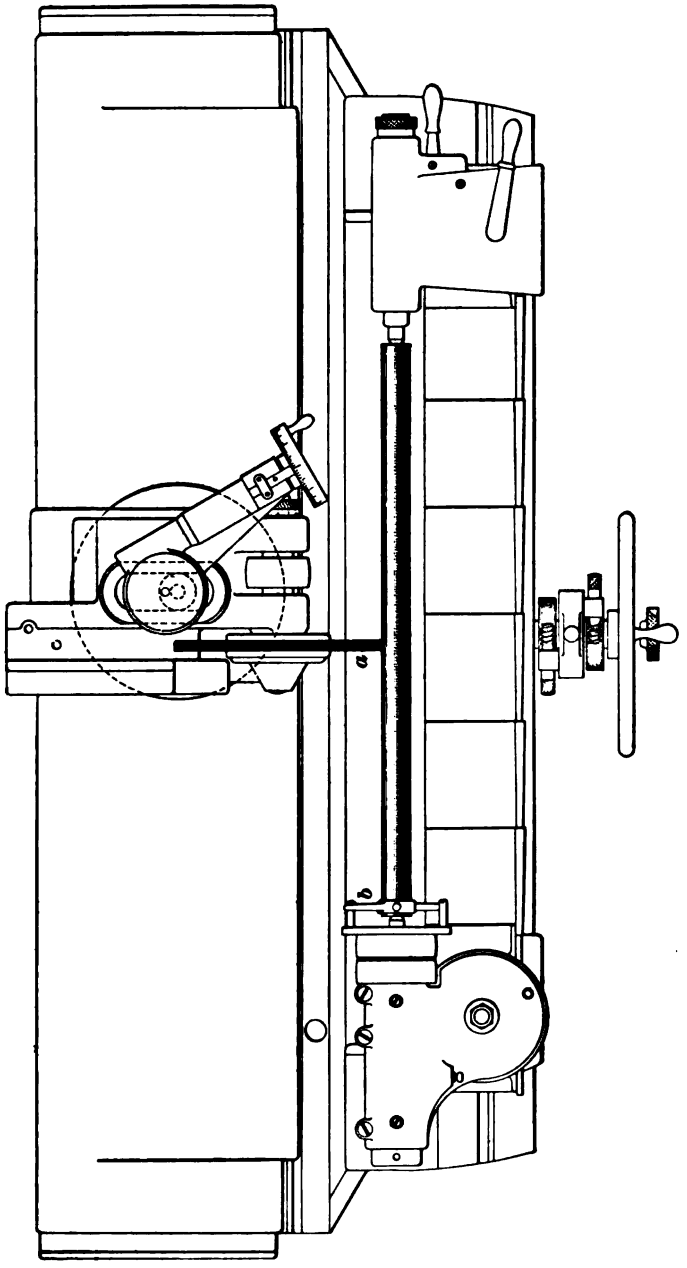


FIG. 8.

show how the machine may be arranged and what shape of wheel may be used to advantage. They may be profitably studied, for the lessons conveyed by them will serve to suggest ways and means of doing work different from that shown.

43. Grinding a Cylindrical Rod.—Fig. 3 shows one of the simplest grinding jobs that is done, which is the grinding of a cylindrical rod between centers. The illustration is a top view of a Landis grinding machine where the table is stationary and the wheel moves past the work. The wheel *a* is set at right angles to the line of motion, so that its cutting surface is cylindrical. In order to grind the work cylindrical, the line of motion of the wheel must be parallel to the axis of rotation of the work, and this condition is obtained by shifting the table until trial shows the work to be cylindrical. The illustration shows the manner of driving the work by means of a dog *b* having two tails that balance each other, though in practice only one of them is in contact with a driving pin. It would be commercially impossible to grind the piece shown without using a number of steady rests, but they are not shown, as they would only complicate the illustration.

44. Facing a Bushing.—In Fig. 4 is shown how a bushing may be faced square. The bushing *c* is placed on

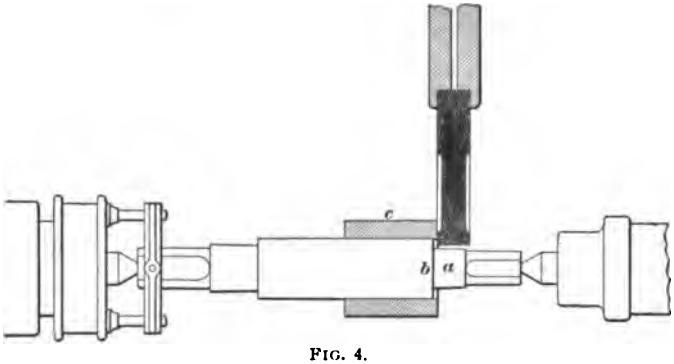


FIG. 4.

a true-running mandrel that is put between the centers and is driven by a dog. In order that the grinding wheel may pass

clear over the end of the bushing, the end *a* of the mandrel should be turned down somewhat smaller than the part fitting the bushing; the latter is then placed on the mandrel

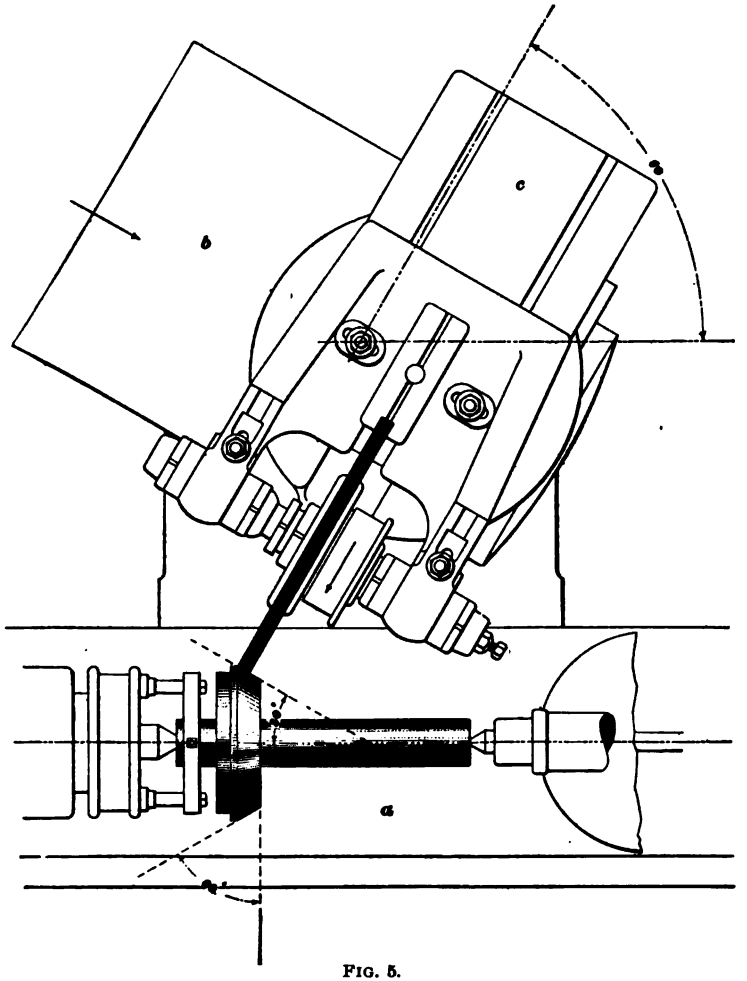


FIG. 5.

so that the face that is to be ground projects somewhat from the shoulder at *b*. Since the grinding must be done by the side of the wheel, the latter should be recessed as shown, leaving only a narrow surface to do the cutting.

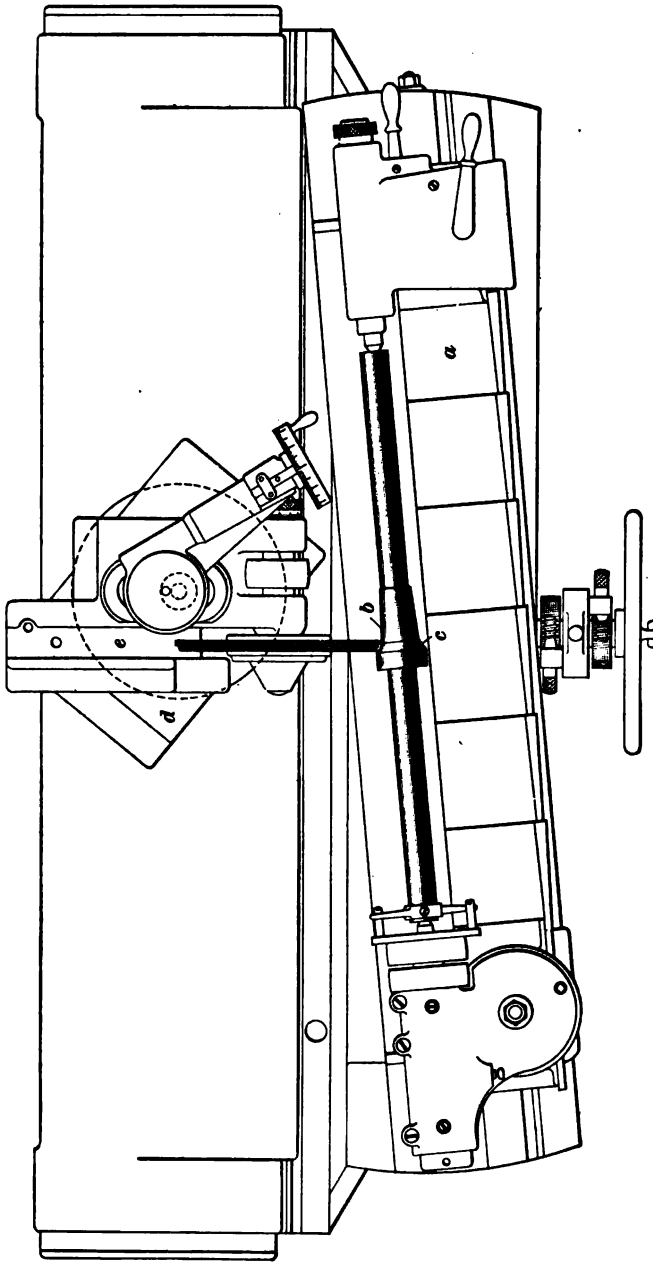


FIG. 6.

The wheel is fed against the face in the direction of the axis of the work; this will generally give a better face than feeding the wheel back and forth across the face of the work.

45. Grinding Conical Work.—The grinding of a short frustum of a cone is shown in Fig. 5, which is a top view of part of a Brown & Sharpe universal machine. The included angle being beyond that attainable by swinging the table *a*, it is gotten by swiveling the lower wheel slide *b* until it makes the required angle to the axis of rotation of the work, the table *a* first having been set to zero, however, in order that the graduations on *b* may give a correct indication. In this case, the upper wheel slide *c* is set at right angles to *b* to allow a square-faced wheel to be used. It will be observed that the slides *b* and *c* form what may be called a compound rest. If the frustum of a cone that is being ground has to be very exact, its accuracy will most likely be tested by a gauge; the final adjustment for the angle is then made by swiveling the table *a* by means of the adjusting screw provided for the purpose.

46. In Fig. 6 is shown how a piece of work having two different conical parts may be ground, where one of the parts is within the range of angles that can be obtained by swiveling the table *a*. Thus, the conical part *b* is ground with the table set over, while the conical part *c* is ground by setting the lower wheel slide *d* to an angle to suit the required angle. It is to be observed that the graduations on *d* will not indicate the angle of *c*, since the table *a* is not at zero. One edge of the grinding wheel is beveled to suit the conical part *c*. The wheel is adjusted for depth of cut by moving it along the upper wheel slide *e*.

When a number of duplicate pieces like that shown in Fig. 6 are to be ground, the sensitive adjustment of the table can only be used for the conical part *b*. The final adjustment for *c* must be gotten by shifting the lower slide *d*. As long a piece as the one shown could not be ground without the use of steady rests.

47. Grinding Close to Shoulder.—An example of grinding a shaft close to a large shoulder is shown in Fig. 7. In this case, the ordinary flat wheel cannot be used, since the nut and the washers used for fastening it to the spindle will come in contact with the shoulder of the work while the wheel is yet some distance from the shoulder. For this

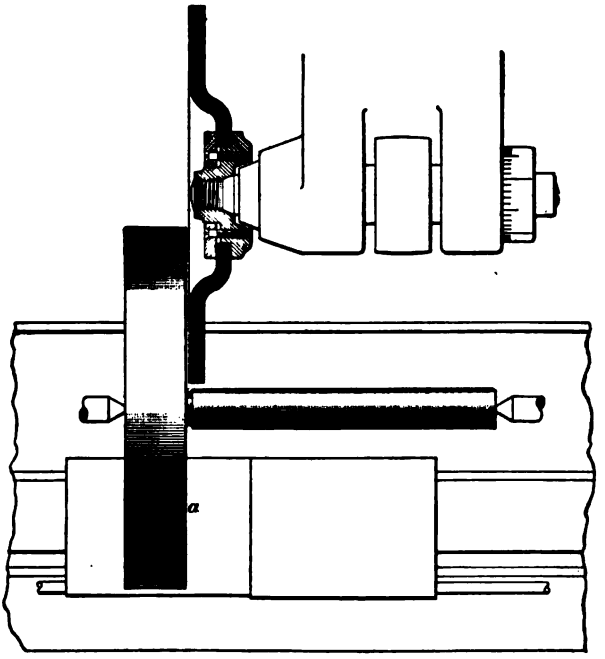


FIG. 7.

reason, the dished wheel shown in the illustration is used. It is not advisable to use such a wheel for grinding the face *a* of the shoulder, owing to the large grinding surface that will be in contact with the work. The wheel cannot clear itself of the particles of metal, and if the shoulder requires grinding, it is better to recess the wheel in order to narrow the grinding surface.

48. Grinding a Caliper Gauge.—The grinding of a caliper gauge is shown in Fig. 8, the illustration being a

partial top view of a Landis grinding machine. The gauge *a* is clamped to the table *b*, which has been set to zero. The wheel slide *c* is set at right angles to the table and a wheel

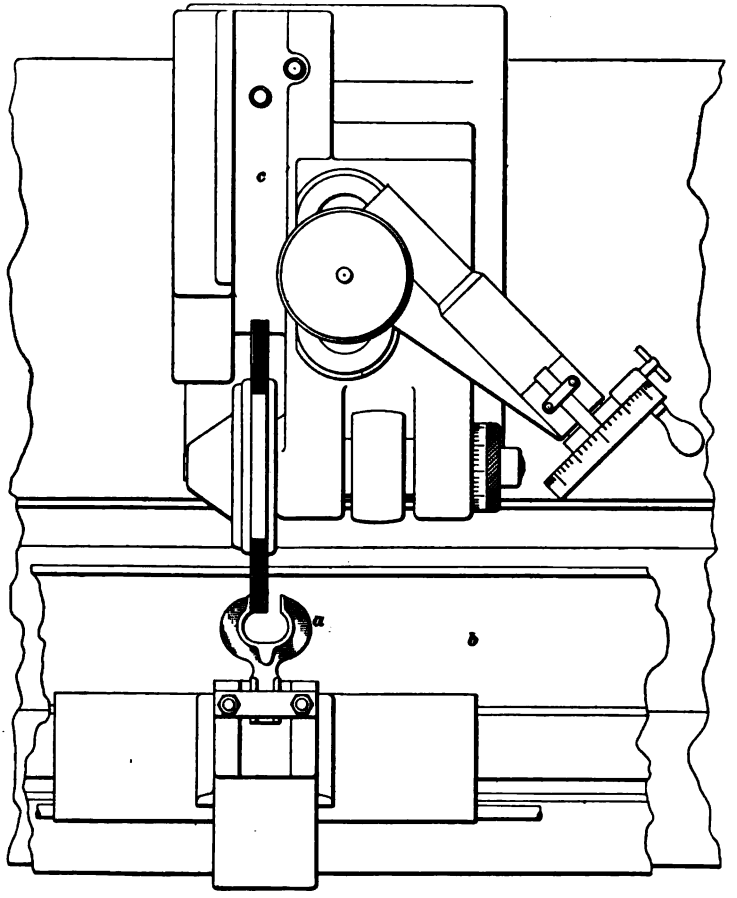


FIG. 8.

recessed as shown is used. The grinding is done by moving the wheel slide rapidly back and forth across the caliper face. A rather soft wheel should be used for this kind of grinding.

It will be noticed that in producing the flat face shown in Fig. 4, the wheel was not moved across the work, while in

the present case it is very necessary to move the wheel across the face of the work. The reason for this is that in the first case the work *c* was revolving, while in Fig. 8 the gauge *a* is standing still.

49. Truing Centers.—Fig. 9 shows how the centers may be trued in a universal grinding machine by swinging the headstock around to make an angle of 30 degrees with the line of motion in order that the centers may be ground

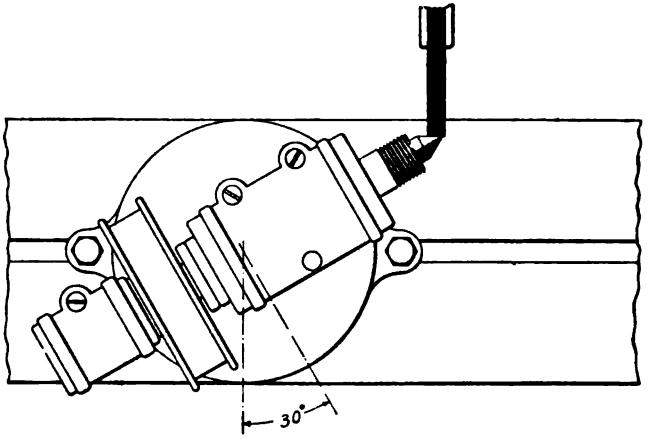


FIG. 9.

to the American standard angle of 60 degrees. In all modern grinding machines, the headstock center and tailstock center interchange, so that both centers may be trued in the headstock spindle. In plain grinding machines, where the headstock cannot be swiveled, the centers are trued by means of a special fixture that is nothing but a supplementary headstock that is removed from the machine after the centers are ground. Obviously the spindle must rotate for center grinding.

50. Chuck Work and Face-Plate Work.—The manner of using a universal grinding machine for chuck work and face-plate work is shown in Fig. 10. When the work is to be ground to a plane surface, the headstock is placed exactly at right angles to the line of motion of the

table or grinding wheel, the table first having been set to zero. The final adjustment is obtained by means of the sensitive adjustment with which the table is supplied, taking trial

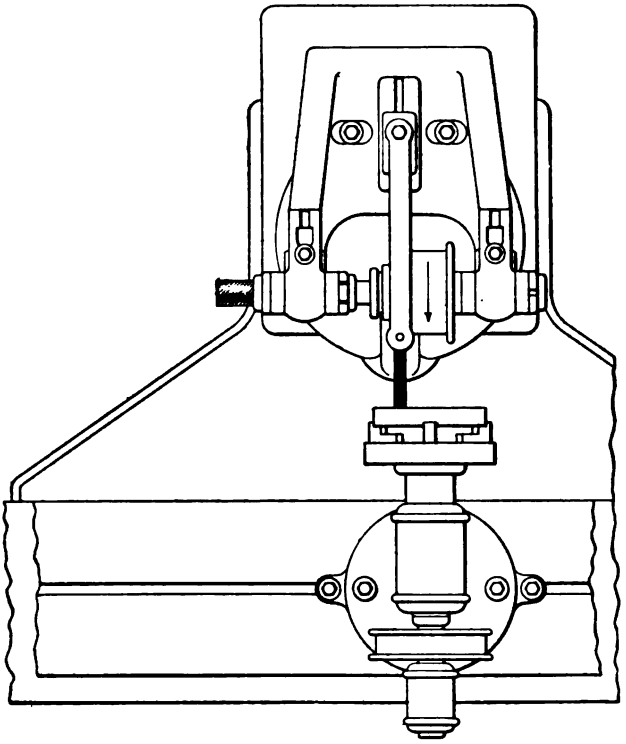


FIG. 10.

cuts over the work and testing it with a straightedge. For conical work the headstock is swiveled to the required angle.

51. Special Chucks.—Thin saws, milling cutters, and similar work that either cannot very readily be held in the chuck or that cannot be attached to a face plate because the clamping devices are in the way of the grinding wheel, can often be successfully held for grinding by means of the special chuck shown in Fig. 11, the use of which presupposes that the work has a fair-sized round hole whose axis is at right angles to the face that is to be ground. A face plate *a*

is screwed to the headstock spindle. A sleeve *b* that is threaded on the inside to fit the screws *c* and *d* is nicely fitted to the central hole of the face plate; this sleeve is axially movable and is kept from turning by a pin that

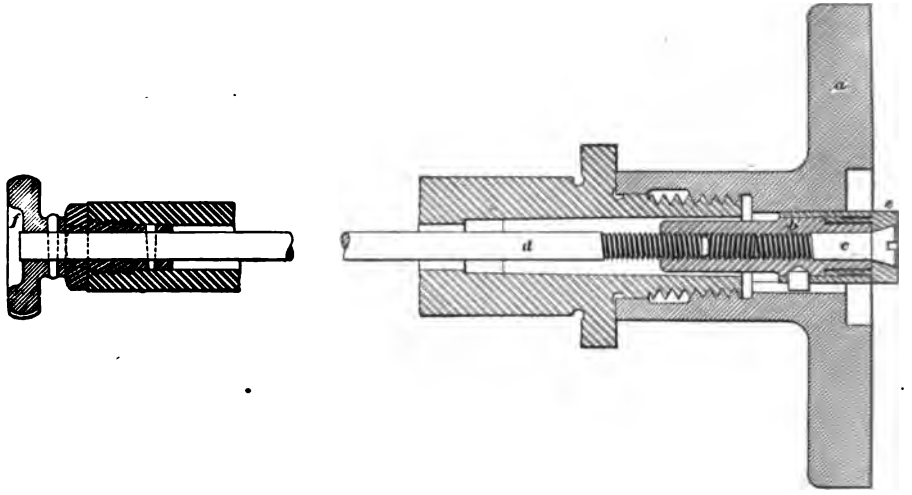


FIG. 11.

works in a longitudinal slot of the face plate. The front end of the sleeve *b* is arranged to take the shank of the bushing *e*, the projecting part of which is fitted to the hole in the work. The bushing *e* is split so that it can be expanded to grip the work tightly by turning the conically headed screw *c*. When this has been done, the work is drawn against the face plate by turning the small hand wheel *f*, which is keyed to the screw *d*. A separate bushing will be required for each size of hole.

THE SET WHEEL.

52. When a large number of duplicate pieces of simple form are to be ground, grinding-machine operators usually employ the so-called **set-wheel method** of grinding. In this method, all the pieces are first roughed out to within a small limit of the finished size, say .001 inch, and then all are finished. In using this method, the operator first sets

the grinding wheel, by trial, to the roughing size, and then, without moving the wheel slide, grinds all the pieces to the roughing size, measuring the work from time to time and moving the wheel toward the work to make up for the wear of the wheel. When all the pieces have been roughed out, the wheel is set, by trial, to grind the work to the finished size and piece after piece is put into the machine and finished without disturbing the setting of the wheel, except to compensate for the wear.

53. For the set-wheel method, a wheel should be selected that will not wear very rapidly; and after all the pieces are roughed out, the wheel should be carefully trued by means of a diamond tool. It will then produce a smooth and even surface on the light finishing cut, although the surfaces produced on the heavy roughing cuts may have been rather coarse.

STEADYING WORK.

54. Purpose of Rests. — When grinding long and comparatively slender work, it is necessary, just as in lathe work, to use some means to prevent the deflection of the work, owing either to its own weight or to the pressure of the cut. For this purpose a follow rest may be used, or a number of steady rests may be applied to the work.

55. Benefits.—The benefits derived from a proper application of rests to the work are: the production of a better quality of work; the possibility of taking heavier cuts and the using of a greater speed and rate of feed; and, finally, an increase in the sizing power of the wheel. The term **sizing power** refers to the ability of the wheel to maintain its size for a fair length of time, which enables it to duplicate a large number of pieces without any movement of the wheel slide.

56. Classification of Rests.—The rapidly increasing use and the consequent development of the grinding machine have led to a great number of designs of rests for the steadying of work while grinding. The different designs

easily divide into two general classes, which may be called *follow rests* and *fixed rests.*

57. A **follow rest** may be defined as a rest that maintains its position in relation to the wheel; i. e., is stationary in respect to it throughout the cut. Such a rest is only adapted to cylindrical work, and for a long time was the only rest supplied to grinding machines.

58. A **fixed rest,** or **back rest,** is a rest that is fastened to the table of the grinding machine, and which, consequently, remains fixed with respect to the work. Such a rest is conceded by most operators to be superior to a follow rest, even for straight work. The fixed rest can also be used on tapered work or work having different diameters. Fixed rests may be divided into two subclasses, which are called *rigid fixed rests* and *flexible fixed rests.*

59. Construction of Rests.—A **rigid fixed rest** is shown in Fig. 12, which also shows its application to the

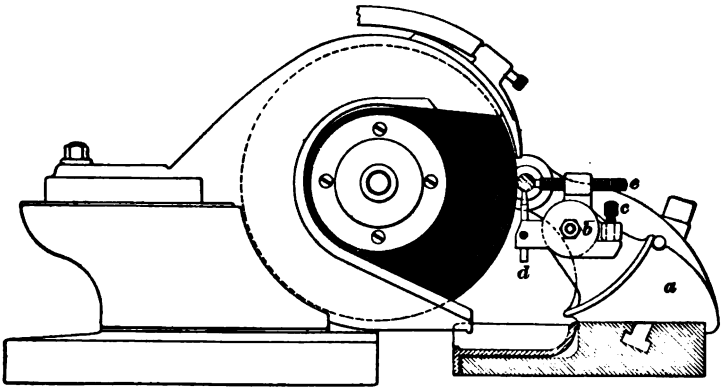


FIG. 12.

work in a Landis machine. The frame *a* of the rest is rigidly bolted to the table; a swinging arm *b* is fulcrumed to the upper part of the frame and can be moved slightly by means of the adjusting screw *c*. An adjustable cylindrical plug *d* is carried by the swinging lever, to which it can be clamped by a setscrew. This plug is placed in contact with

the bottom of the work, the sensitive adjustment being obtained by the screw *c*, and the rough adjustment, for the diameter of the work, by sliding the plug in the lever. A setscrew *e* is used for steadying the work sidewise.

60. When using a rigid rest, it is not necessary for the operator to spot the work at the place where the rest is applied. The rest is simply applied to the work and grinding commenced. The emery wheel will cut more from the high side, even though the rest may appear to hold the work so that it runs true, and the work will finally come out round and straight. Care must be exercised in adjusting the parts of a rigid rest, as *d* and *e*, for a very little pressure will deflect a slender bar, and if the rest is set up too hard the work may be ground small in the middle. As the diameter of the work is reduced, a rigid rest must be readjusted.

61. Flexible fixed rests are made in various ways; the simplest form is the so-called **spring rest** shown in Fig. 13. The frame *a* is fastened to the table of the machine; it has a rectangular recess at the top into which the rectangular shank of the shoe *b* is so fitted as to move easily. The end of the shoe that bears against the work is curved to suit the diameter of it; the rear end of the shoe is acted upon by a helical spring *c* whose tension can be adjusted by means of the thumbscrew *d*. The shoe should be made of some soft material, as brass, babbitt, or wood. This kind of a rest reduces or eliminates the vibration of the work by reason of the inertia of the shoe and the tension of the spring *c*; it is open to the objection, however, that too great a tension of the spring will cause the work to be bent. On the other hand, the spring will cause the shoe to follow up automatically any

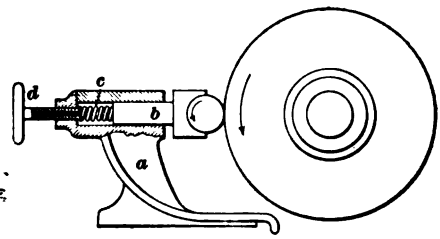


FIG. 18.

reasonable reduction in the diameter of the work. The shoe should never be made of any hard material, as it should wear rapidly to a good fit, on account of the fact that the value of the shoe in absorbing vibrations depends largely on the degree of its contact with the work.

62. The **universal back rest** supplied by the Brown & Sharpe Manufacturing Company with their plain grinding

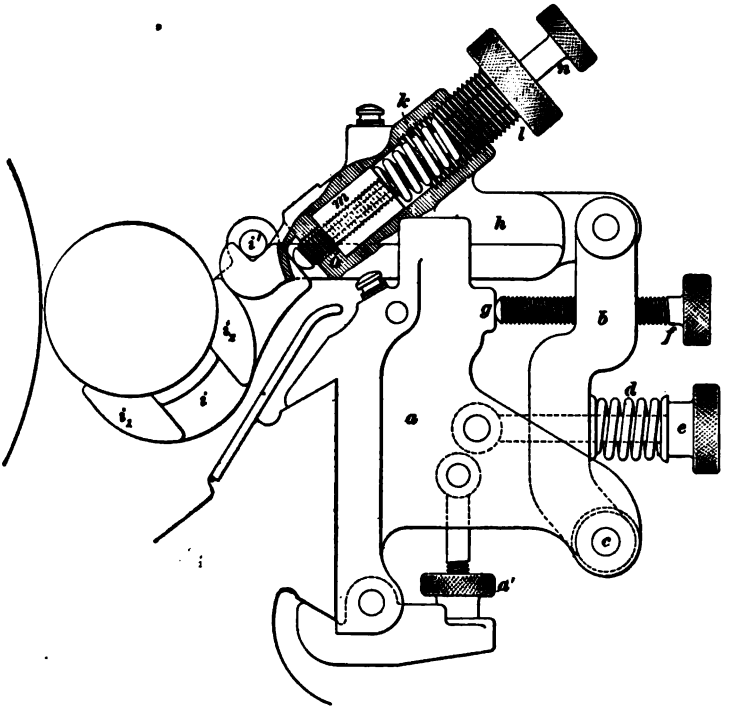


FIG. 14.

machines is shown in Fig. 14. The back rest for the universal machines works on the same principle, but is constructed quite differently. The frame *a* is clamped to the table of the machine by turning the nut *a'*. A swinging lever *b* is pivoted to the frame at *c*; a spring *d*, whose tension can be adjusted by the thumbnut *e*, tends to force the upper end of *b* toward the work. The extent to which the lever

can move toward the work is regulated by the thumbscrew *f*, whose end, by coming in contact with a shoulder *g* of the frame, limits the motion of *b*. The shoe-carrying frame *h* is hinged to the upper end of the lever *b*, and the front end of *h* rests on a part of the frame *a*. This construction allows the frame *h* to move toward the work to the extent permitted by the position of the screw *f*, but does not permit the front end of *h* to drop. The shoe *i* has trunnions, as *i'*, which rest in V notches formed at the front end of *h*. The shoe is held against the work by a helical spring *k*, whose tension is adjusted by the thumbnut *l*. The spring *k* bears against the movable nut *m*, which carries the adjusting screw *n*, the end of which bears against the shoe. From the construction it follows that the action of the spring *k* causes a rotation of the shoe *i* about *i'*, thus tending to draw the part i_1 of the shoe against the work. The screw *n* passes through a clearance hole in the thumbnut *l*, and its axial motion under the action of the spring *k* is limited by the lower face of the nut *m* coming against a shoulder *o* of the shoe-carrying frame.

63. From the construction of the device it follows that the part i_2 of the shoe is held against the work by the spring *d*, while i_1 is held against the work by the spring *k*. It also follows from the construction that the pressure of the shoe against the work can be arrested at a predetermined diameter by a proper adjustment of *m* and *f* in respect to the shoulders *g* and *o*. If these adjustments are properly made, it is impossible for the springs to bend the work. Different sizes of shoes will be required for different diameters of the work; since the shoes are removed by simply lifting them out of the V's in the frame *h*, they are readily changed.

64. Since the shoe is operated by spring pressure in two directions at right angles to each other, it can yield to suit the inequalities of unground work, and, hence, there is no necessity of grinding the work to run true at the place where the rest is applied, prior to the application.

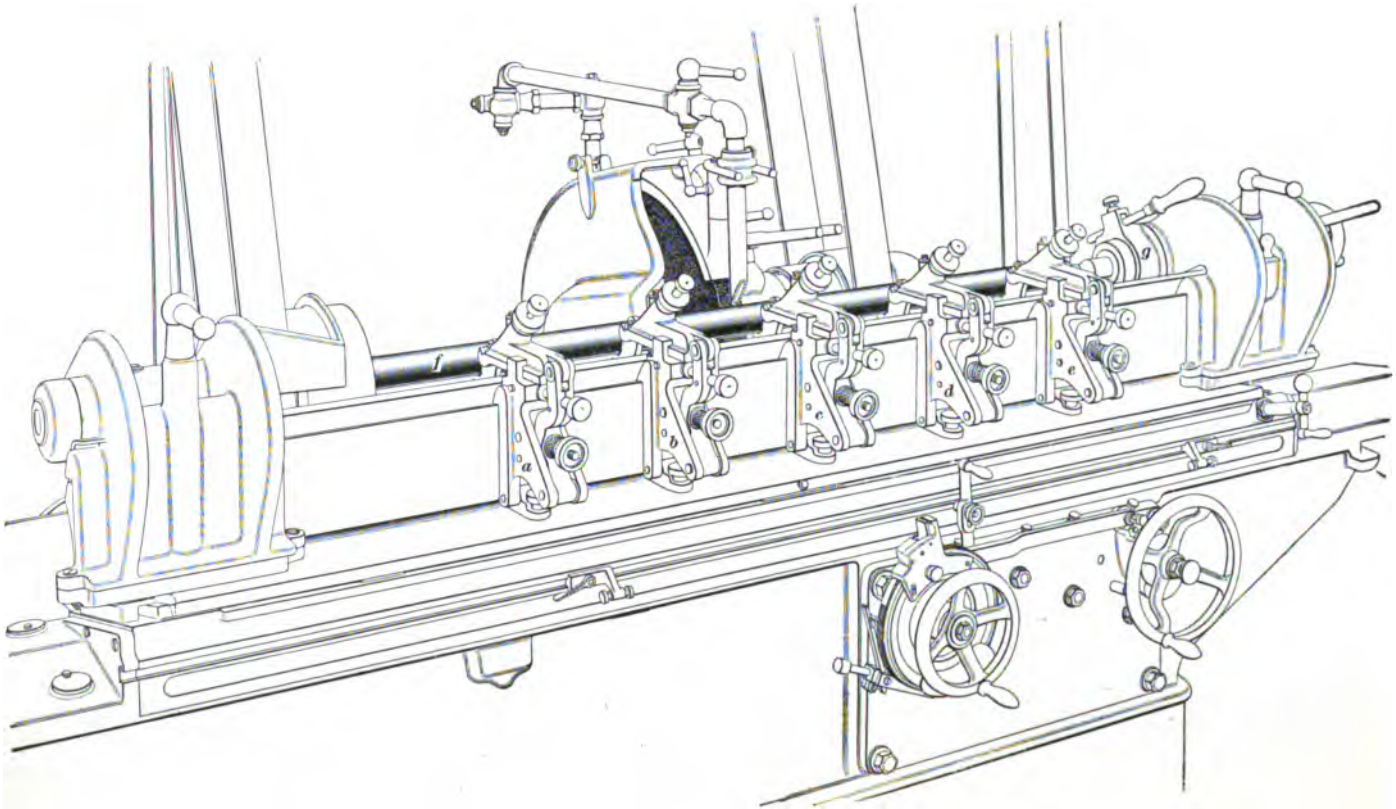


FIG. 15.

65. Application of Universal Rests.—Fig. 15 is a perspective view of a plain grinding-machine, showing how the universal rests are applied to a long piece of work. In order to steady the work *f*, a number of rests, as *a*, *b*, *c*, *d*, and *e*, are used, which are placed from 6 to 8 diameters of the work apart. Each rest is independently adjusted to properly bear against the work. This illustration incidentally shows on the footstock a truing device *g* for holding a diamond-pointed tool. As clearly shown, the tool is held in place by a small thumbscrew; in use the depth of cut is obtained by moving the wheel slide, and the grinding wheel is moved back and forth past the tool.

66. Absorption of Vibration.—When comparatively stiff work that is being ground without a rest commences to vibrate, as occurs occasionally, the vibrations can sometimes be absorbed by holding a block of wood against the work by hand, resting one end of the block on the table. This is only a makeshift to be used where single pieces are being ground. In doing commercial work, a rest should always be used. Whenever a piece of work or a wheel commences to vibrate, the cause should be looked up and the proper remedy applied. The vibration may be caused by a glazed wheel, improper speed of wheel or work, or irregularities in the stock.

67. Special Rests.—Where a large number of duplicate pieces are to be ground, special rests can often be advantageously used. These rests must usually be of the fixed-rest type, and may be rigid rests or spring rests. Their design rarely presents any difficulties, as they are generally but simple modifications of the rests here described, the modification having been made necessary by the shape of the work.

POOLE METHOD OF CYLINDRICAL GRINDING.

68. As is well known, a round bar may show under very refined measurements as being exactly round and of uniform diameter, and may yet be far from straight; that

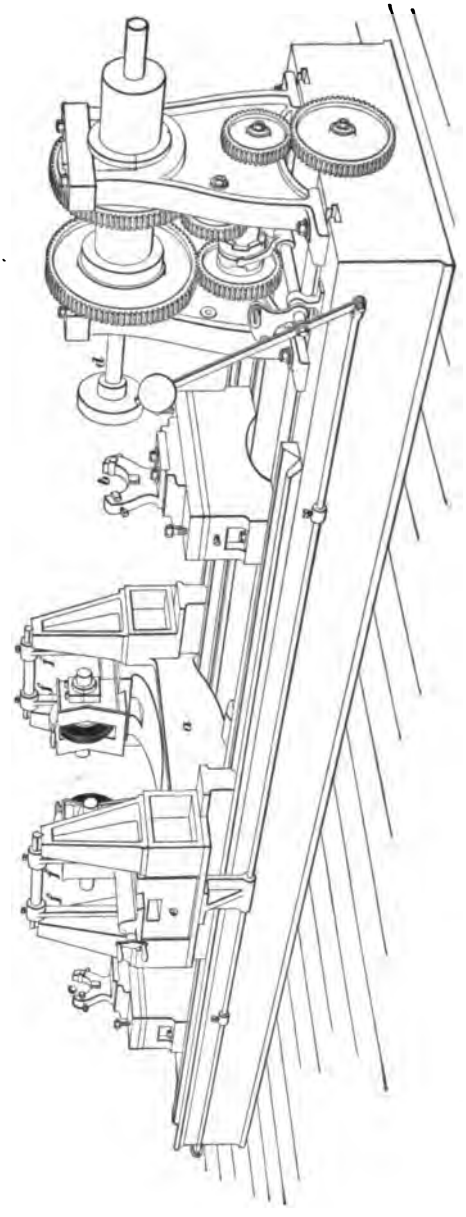


FIG. 16.

is, it may be far from a true cylinder. In all ordinary grinding machines, the straightness of the work depends primarily on the straightness of the guiding ways that determine the line of motion of the wheel or the work, and while the work may be round in spite of a want of truth of the guiding ways, any error in them is bound to produce work that is not straight. While it is not a very difficult matter to produce straight guiding ways in small grinding machines intended for comparatively light work, the problem becomes more difficult when a machine suitable for the grinding of such work as the calender rolls used in paper making is to be constructed. Such rolls are quite large and must be exceedingly straight and uniform in diameter; on account of the difficulty of making the guiding ways sufficiently true, Mr. J. Morton Poole devised a special method of grinding that largely overcomes any reasonable error that would be induced by want of straightness of the guiding ways. In the Poole method of grinding, the periphery of the grinding wheel is kept at a constant distance from the axis of rotation of the work, not by the straightness of the guiding ways, but by gravity, as will become apparent when the construction of the machine is studied.

69. Fig. 16 is a perspective view of the machine, which in some respects resembles a lathe with the tailstock left off. The carriage *a* that carries the grinding wheels is mounted on V's, along which it can be traversed. The roll that is to be finished has its two journals ground perfectly true and these journals are placed in the jaws of the steady rests *b* and *c*. The jaws of these rests are both the same height above the guiding ways. The work is driven from the headstock spindle *d* by means of a flexible connection, in order that any want of alinement between the axes of rotation of the work and the spindle may not disturb the former during grinding. Two grinding wheels are used on opposite sides of the work; each grinding wheel is mounted on its own wheel slide. The two slides work in a heavy casting *e* that forms their base; this casting is supported by four links,

as *f*, *f*, from the top of the carriage by means of knife-edge bearings. This construction allows the grinding wheels to swing freely in a direction at right angles to the axis of rotation of the work, and the wheels will obviously be at rest when the center of gravity of the whole swinging part occupies its lowest position.

70. The distance that the grinding wheels are apart during each cut being constant, it follows that the roll being ground will be of uniform diameter throughout, neglecting here the wear of the grinding wheels which will be exceedingly small during a light finishing cut. Now, as stated in Art. **68,** a bar may be apparently round and of uniform diameter without being straight. Any one who is in doubt about this statement is advised to take a straight piece of drill rod, which, as supplied by manufacturers, is quite round and exceedingly uniform in diameter, and to bend it slightly. It will then be found that with a reasonable amount of bending the piece will caliper the same throughout its length. While there is no doubt but that the diameter and also the roundness of the piece are changed by the bending, the fact remains that the change is so slight, when the bend is not excessive, as to be insensible.

71. Assume that the roll being ground is not exactly straight. Then, when revolved in the steady rests *b* and *c*, it will run out of true, and the high side coming toward one of the emery wheels will tend to push over the swinging frame. This tendency is resisted by the weight of the swinging frame, and, consequently, there is a pressure, dependent on the amount that the roll runs out of true, that causes the wheels to alternately cut away the high side until the center of gravity of the swinging frame is in its lowest position again, when the wheel ceases to cut. It will be understood that the frame swings back and forth as the high side of the revolving roll engages one or the other of the two grinding wheels. By repeated passages of the carriage along the bed, the roll is finally so ground as to run perfectly true; and as the fixed distance between the wheels

insures a uniform diameter, the finished roll becomes a very close approach to a perfect cylinder, independently of the truth of the guiding ways. In practice the operator takes most or all of the swing out of the carriage while roughing the roll. On the whole, this is a rather slow process, though it produces very good work. Some classes of rolls have to be ground large or small in the middle. This may be done by raising or lowering the swinging carriage at the proper points so as to bring the wheels above or below the center of the roll. As soon as the wheels are removed from the center of the work they will grind large.

INTERNAL GRINDING.

INTRODUCTION.

72. Internal grinding presents problems of a practical nature that differ somewhat from those encountered in external grinding; since a knowledge of the causes of these problems is essential to their partial or entire solution, they are here briefly explained.

73. Influence of Pressure.—In internal grinding the truth of the surfaces, at least as far as the grinding itself is concerned, depends primarily on the amount of pressure caused by the grinding operation As in the case of external work, this pressure tends to disturb the position of the axes of rotation of the work and the grinding wheel; since the amount of disturbance depends directly on the pressure, it follows that a reduction of it to the lowest limit attainable with a given set of conditions causes a corresponding reduction of errors and a consequent increase in the truth of the work.

74. Pressure Greater Than in External Grinding.—The pressure required to make the wheel cut is always greater in internal grinding than in external grinding, especially when the hole that is being ground is small. The

reason of this is the more intimate contact of the grinding wheel with the surface of the work; the extent of this contact will become apparent when a grinding wheel but slightly smaller than the hole is employed. It may be stated that for equal depths of cut, equal diameters of wheels, equal diameters of the work, and equal widths of the wheels, the extent of the surface of the wheel in contact with the work will always be greater in internal grinding than in external grinding. This is shown in Fig. 17, where a cylinder *a* and a cylindrical ring *b* having the same diameter of the surface to be ground, are illustrated. The grinding wheels *c* and *d* have the same diameter, and both are set for the same depth of cut. It is plainly seen that the surface with which the wheel is in contact is greatest in internal grinding, and it can be readily understood that the pressure of the cutting operation will be greater than in external grinding. From these facts the conclusion may readily be drawn that in order to reduce the pressure of the cut, the depth should be much less in internal than in external grinding.

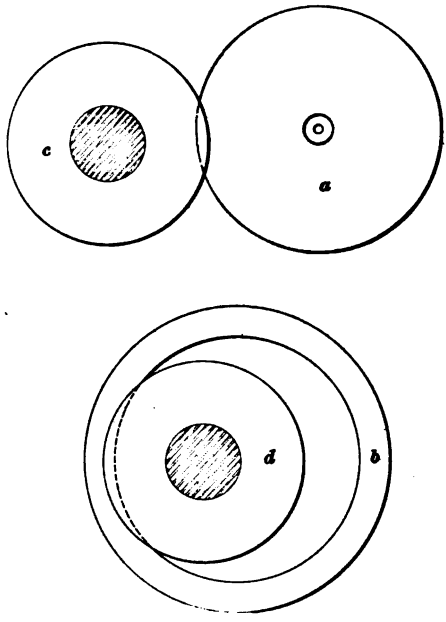


FIG. 17.

75. Best Cutting Speed Cannot Be Obtained.— The grinding wheel obviously must be smaller than the hole in which it is to be used, and a very small hole requires a very small wheel. In order to obtain the best cutting speed, the

wheel would have to be run at a very high number of revolutions per minute. While it has been found possible in practice to run a very small grinding spindle of exquisite workmanship at the enormous rate of 75,000 revolutions per minute, even this high rate of speed falls very much short of giving the best surface speed to the grinding wheel. At present the art of making a spindle and bearings for it to run at the number of revolutions that would produce a proper surface speed has not progressed far enough to allow this to be done, at least for small holes.

76. When a grinding wheel is run at a surface speed below its best cutting speed, more pressure will be required to make it cut, but as the required pressure is less with a soft wheel than with a hard one, it follows that a softer wheel should be used whenever circumstances prevent the attainment of a proper surface speed. Since the condition just named exists usually in internal grinding, it follows that much softer wheels should be used than for external grinding, in order to reduce the pressure.

77. Considerations Affecting Stiffness of Spindle.—In the case of external grinding, the spindle that carries the grinding wheel can always be made as stiff as may be desired; in the case of internal grinding, however, the size of the hole that is to be ground determines the maximum diameter of the spindle. Then, if the hole is small and deep, the spindle must be correspondingly small and slender; consequently, it is bound to yield to a sensible extent under a very moderate pressure. From the statements just made, it will be apparent that in order to reduce the deflection of the spindle, it should be as large as circumstances will permit, and be supported close to the grinding wheel.

78. In the earliest designs of internal-grinding fixtures, a spindle of as large diameter as possible was employed, and the distance from the wheel to the nearest support was at least equal to the depth of hole to be ground. It was soon found, however, that while the requisite stiffness was

obtained, another serious error not previously thought of was introduced. This error was due to the looseness of the spindle in its bearings, which is necessary for free running, but which shows much greater at the end of the spindle by reason of the long distance between the wheel and the nearest bearing. The consequent wabbling of the wheel caused it to follow the imperfections of the hole being ground and precluded the grinding of a true hole.

79. When the spindle is made as large as the hole will permit, it is obviously impossible to place a bearing adjacent to the emery wheel. Hence, in order to place a bearing in that position, the diameter of the spindle must be cut down; and to give the requisite stiffness, the bearing must be of such a form that it will make up for the reduced diameter of the spindle. This consideration requires the bearing to be a cylindrical shell carrying the spindle inside and having its outside diameter slightly smaller than the diameter of the smallest hole in which the internal-grinding fixture is to be used. Then, if the bearing is directly back of the grinding wheel, its possible side movement will exceed but slightly the side movement (the looseness) of the spindle in its bearing.

80. Construction of an Internal-Grinding Fixture.—The Brown & Sharpe Manufacturing Company was

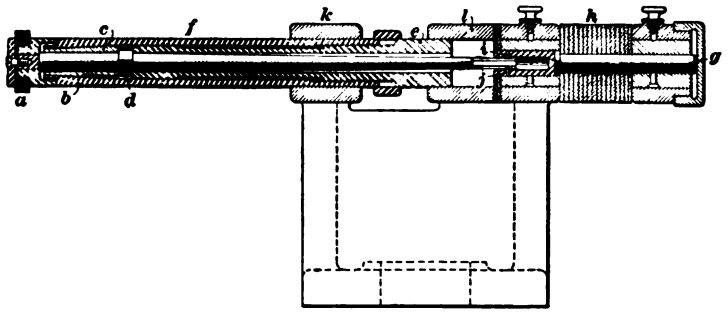


FIG. 18.

the first firm to construct an internal-grinding fixture along the lines mentioned in Art. **79.** This fixture is shown in

section in Fig. 18. The grinding wheel *a* is carried by the spindle *b*, which has a long journal working in a split-bronze bearing *c*. The spindle is held in place lengthwise by the collar *d*, which bears against the end of *c* on one side, and on the other side bears against the end of the tube *e*. The outside of the bearing *c* is tapered and fits the tapering bore of the supporting shell *f*. The wear of the bearing is taken up by screwing the tube *e* into the shell, thus causing the bearing to close. The tube *e* is then slightly unscrewed to give

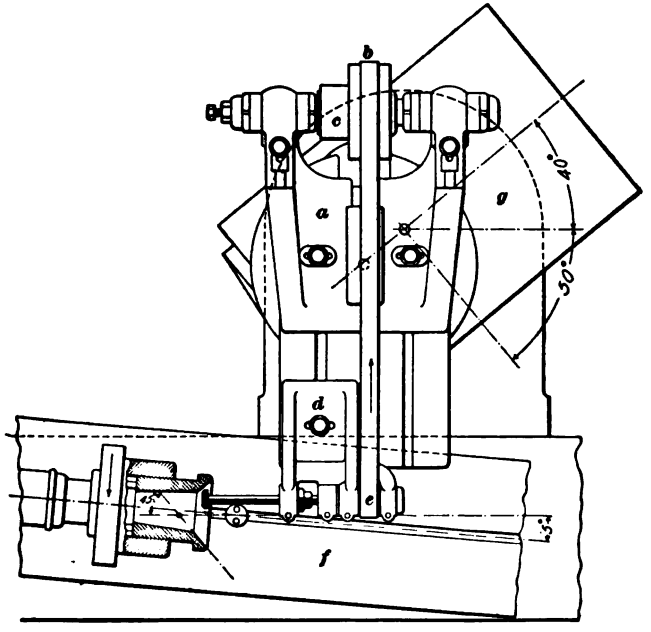


FIG. 19.

the collar *d* a free running fit. The end of the spindle is splined and fits loosely in a central hole of the driving shaft *g*, which carries the driving pulley *h*. Two pins *i* and *j* engage the splined end of the spindle and cause it to turn with the driving shaft. The outer shell *f* and the end of the tube *e* are sliding fits in the bearings *k* and *l*, and *f* can be clamped to *k*. This construction permits the wheel *a* to

be brought somewhat closer to the bearing *k* for shallow holes.

81. Driving the Spindle.—The method of driving the spindle for internal grinding is shown in Fig. 19. The grinding wheel is removed from the wheel stand *a* and a driving pulley *b* is put in its place. The wheel stand *a* is then reversed, so that it occupies the position shown in the illustration. The pulley *c* is now belted to the drum overhead. The internal-grinding fixture *d* is bolted to the wheel slide; its spindle is then driven by belting its driving pulley *e* to the pulley *b*.

METHODS OF GRINDING.

82. Grinding Conical Work.—Fig. 19 shows how the universal machine is used for grinding a hole having a double taper; i. e., whose surfaces form frustums of two different cones. The table *f* is swung around to grind the smaller taper, and the wheel slide *g* is set over in order to grind the larger taper.

When the machine has a swivel headstock, one taper might be ground by setting over the headstock, leaving the table at zero. The other taper is then ground by setting over the wheel slide, or changing the setting of the headstock.

83. Fig. 20 shows how a tapering hole in the end of a spindle may be ground to run true with the outside. One end of the spindle is held in the independent jaw chuck *a*, while the other end is run in the center rest *b*. For testing the truth of the end of the spindle that is held in the chuck, a sensitive indicator should be used, the operator revolving the headstock spindle by hand and truing the work until the indicator shows it to run dead true. The center rest insures that the other end of the spindle runs true. The proper taper is obtained by setting over the table. When adjusting the center rest, great care must be taken that the work is not thrown out of alinement with the

axis of rotation of the headstock spindle, for if this is done, the jaws of the chuck will badly mar the end of the work, and besides the work is likely to creep slowly forwards in the direction of its length during the grinding. The jaws of

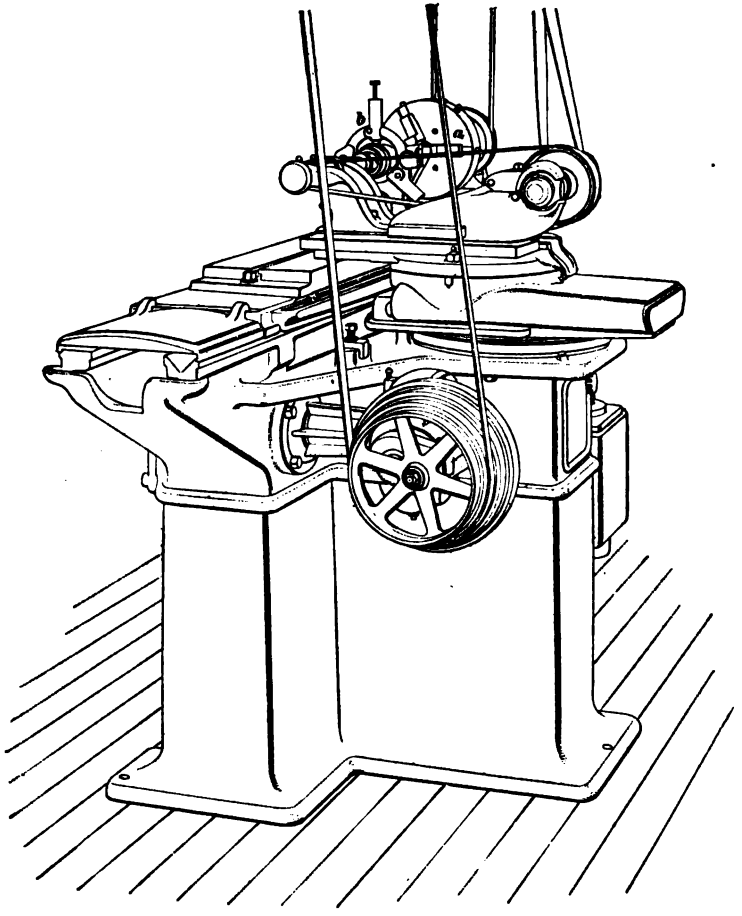


FIG 20

the center rest should touch the outside of the work just enough to prevent any shaking. If they are set up too tight, the work will heat very rapidly, and since it expands

with the heat, it will cause a still greater pressure on the ends of the jaws, which may score the work.

84. Chucks.—Universal chucks are not to be recommended for grinding machines, because they will not hold the work true enough for the purpose. Independent jaw chucks are preferable in every respect, since they not only allow the work to be trued carefully, but, also, frequently permit hardened work having a small grinding allowance to be trued to suit the warping induced by the hardening process. If such work is held in a universal chuck, it will often be impossible to finish it to size with the given grinding allowance, owing to the lack of truth in the chuck itself and the inability to true the work to suit the warping.

85. It sometimes occurs that a shell or thin cylinder cannot be trued sufficiently in the ordinary independent jaw chuck. In that case a so-called **bell chuck** may be used. This form has the advantage over the jawed chuck in that it allows both ends of the work to be trued independently of each other. Such a chuck is shown in perspective in Fig. 21. Its rear end *a* is threaded to fit the headstock spindle; the body *b* is bored sufficiently large and deep to freely admit the work, and eight thumbscrews that are placed as shown are used for holding the work and adjusting it so that it will run true.

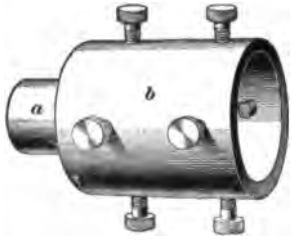


FIG. 21.

86. For special work that is to be done in large quantities, special chucks may be made to advantage. The general form of such chucks is about the same as those used for screw-machine work and turret-lathe work. It is probable that many forms of work made of iron and soft steel and that are held by ordinary chucks at present will in the future be held by magnetic chucks. These magnetic chucks

not only hold the work securely, but are not so liable to bend or spring the work as the present methods of clamping.

87. Face-Plate Work.—For the internal grinding of work whose form requires it to be held on a face plate, the work is held by the same clamping devices used in lathe work; these are applied in the same manner as in lathe work, and the truing is performed in the same way. It must always be remembered, however, that grinding is a very refined process of finishing the work, and that great care should be taken not to bend the work by clamping.

SURFACE GRINDING.

88. Grinding on Planer. — The grinding of plane surfaces was formerly done, and is yet largely done, on an ordinary planer, which is temporarily converted into a surface-grinding machine by mounting an emery wheel on the cross-rail and providing an overhead drum for driving it. With a planer in good condition, very good work can be done in this manner.

Regular surface-grinding machines are now made; in general appearance and in their manner of operation they greatly resemble the ordinary metal planer, and, in fact, may be said to occupy the same state at present with respect to the planer that the first grinding machine for solids of revolution occupied with respect to the lathe.

89. Present State of Art.—The art of surface grinding has not at present reached the high state of perfection as has the grinding of solids of revolution; and while it is a refined process of finishing surfaces, it is not capable of competing with planing in the removal of metal. As far as hardened work is concerned, it is the only practical method of producing plane surfaces in a reasonable time. For the most refined work, the grinding would be followed by lapping, just as with solids of revolution.

90. Surface-Grinding Machine.—Fig. 22 shows a surface-grinding machine made by the Brown & Sharpe Manufacturing Company. The illustration will show its general resemblance to the planer, from which it differs only

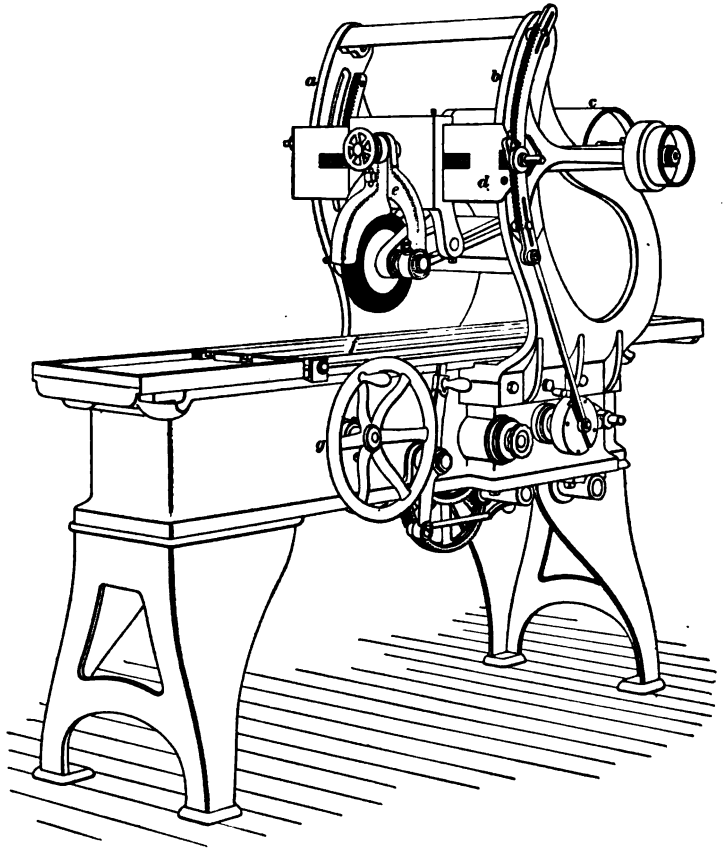


FIG. 22.

in the curved housings *a* and *b*. The face of these housings is an arc of a circle struck from the center of the driving drum *c*; from this it follows that the tension of the wheel driving belt will remain constant throughout the whole range of movement of the crosshead *d*. The crosshead slide carries the wheel head *e*, which can be automatically fed

across the machine. The table *f* is arranged to be traversed by hand by means of the hand wheel *g*, but it may also be automatically traversed. The stroke of the table is adjustable for length and position by means of tappets that operate a suitable clutch mechanism. Surface-grinding machines of the type shown in Fig. 22 are at present adapted only for grinding surfaces parallel to the surface of the table.

91. Selection of Wheels.—The wheels for surface grinding should always be softer than those used for grinding solids of revolution in order to reduce the pressure of the cutting operation and the consequent generation of heat. In surface grinding only one side of the work is operated upon, and, consequently, the work, with any increase in the temperature, will rise up in the center. Since surface-grinding machines for fine work are not at present constructed to use water, it is necessary to keep the generation of heat down by a proper selection of grinding wheel, and thus prevent too serious a change in the shape of the work.

92. Holding the Work.—The work is held to the table of a surface-grinding machine by the same holding devices and in the same manner as is done in planer, shaper, and milling-machine work. For many kinds of work, the magnetic chuck may be used successfully.

CUTTER AND REAMER GRINDING.

PURPOSE OF TOOL GRINDING.

93. When making milling cutters and reamers, it is necessary to grind them so as to give them true cutting edges. It is also necessary to grind such tools when they become dull to maintain them in the best serviceable condition. The condition of all cutting tools should be watched carefully, because when a tool or cutter begins to get dull, if it is not immediately sharpened it soon becomes worse, and requires more power to drive it. Furthermore, the

increased friction produces sufficient heat to seriously affect the temper of the tool.

Most tools when but slightly dulled may be ground many times without injury either to their form or temper. This is especially true of the formed cutters, of which the gear-cutter is perhaps the most common type. These cutters may be ground on the faces of the teeth, as long as the teeth last, without changing their form; and if kept in good condition, a very slight grinding is sufficient to sharpen the cutter; but, if the cutter is kept at work when dull, the formed surfaces become worn back from the cutting edge, thus necessitating the removal of $\frac{1}{32}$ inch or more from the faces of the teeth in order to sharpen them.

THE MACHINE.

94. Cutter and reamer grinding is usually done on specially designed machines, but it may be done on the universal grinding machine. Several of these cutter grinders have most of the movements of the universal grinding machine; such cutter grinders will then serve for a large variety of small work that is generally done in the universal grinding machine. The essential features of a cutter grinder are a spindle carrying a small emery wheel that may be revolved at from 2,500 to 5,000 revolutions per minute, and suitable holders and guides for holding and guiding the tools in the correct position. A small table, or rest, is usually provided in front of the wheel on which flat or formed cutters may be held while being ground.

95. The machine shown in Fig. 23 is a cutter and reamer grinder made by the Norton Emery Wheel Company, and arranged only for the sharpening of milling cutters and reamers. This machine consists of a column *a* that carries the wheel stand *b*; this is arranged in such a manner that it can be swiveled. A graduated saddle *c* is placed on top of the column; this saddle carries the slide *d* in which the table *e* works. The table can be moved toward or away

from the grinding wheel by means of a feed-screw that is operated by the hand wheel *f*. The table can be swiveled horizontally, the saddle *c* having graduations that show the

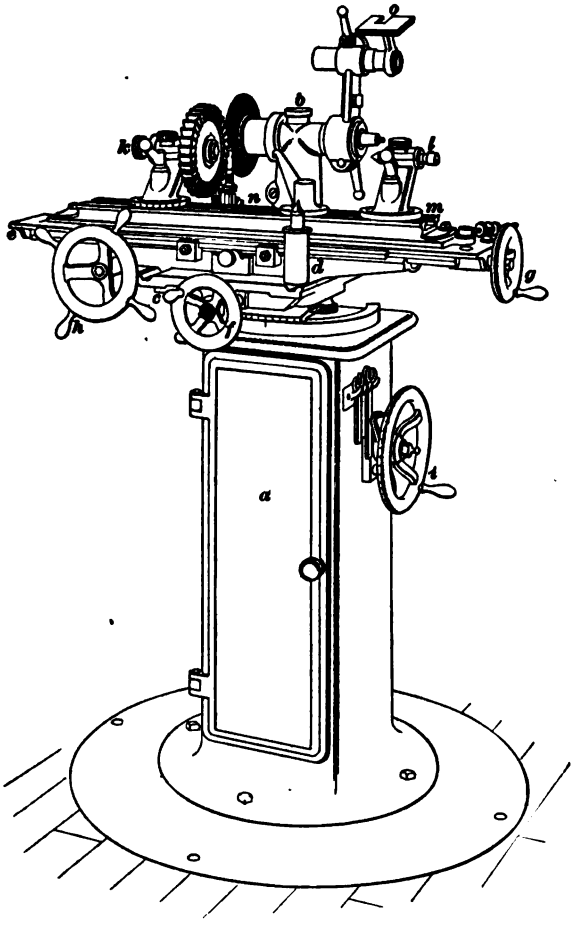


FIG. 23.

angle between its line of motion and the axis of rotation of the spindle. A feed-screw that works in a split nut and is operated by the hand wheel *g* is used for traversing the table; when the split nut is unlocked from the feed-screw, the table can be traversed rapidly by means of the pilot

wheel *h*. The height of the emery wheel above the table can be adjusted by means of the hand wheel *i*. A headstock *k* and a footstock *l* are provided for grinding work between centers. The headstock and footstock are attached to an auxiliary swivel table *m*, which is placed on top of the regular table *e*; this adapts the machine for taper work to be done between centers. An adjustable standard *n* for a guide finger is provided; this finger prevents rotation of the cutter or reamer that is being ground. A small rest *o* is intended for the grinding of formed cutters, which are laid on the rest and presented to the grinding wheel by hand.

96. If a driving pulley is fitted to the headstock, the machine may be used for grinding small cylindrical and taper work between centers, and by the aid of proper attachments chuck work and internal grinding of a light kind may be done. Since the wheel stand may be swiveled to bring the wheel over the table, the machine may be used for light surface grinding.

97. Cutter and reamer grinding machines are made in different ways by the various manufacturers, but most of them embody the same features and differ only in the design of the details. The illustrations and examples of cutter and reamer grinding that are given in the following articles do not refer to any particular make of machine, but have been selected entirely for the sake of the principle involved in each operation. This fact is mentioned here in order that the reader may not think that the illustrations and explanations given refer to the machine shown in Fig. 23.

EXAMPLES OF CUTTER AND REAMER GRINDING.

GRINDING CYLINDRICAL CUTTERS.

98. Cutter Bar.—Fig. 24 is an example of grinding a cylindrical milling cutter in a machine somewhat different from that shown in Fig. 23. In the illustration, which is a top view, the emery wheel *a* is shown mounted on the

spindle *b*; beneath the emery wheel is a guide finger *c*. Clamps *d*, *d* hold a cutter rod or bar *e* on which the cutter *f* is mounted. A helical groove is sometimes cut in the cutter bar *e*, so that any particles of emery that may collect on the bar will be brushed into the groove by the backward and forward movement of the cutter. Since the size of the holes in milling cutters varies with their diameter, it follows that some provision must be made for grinding all sizes of cutters

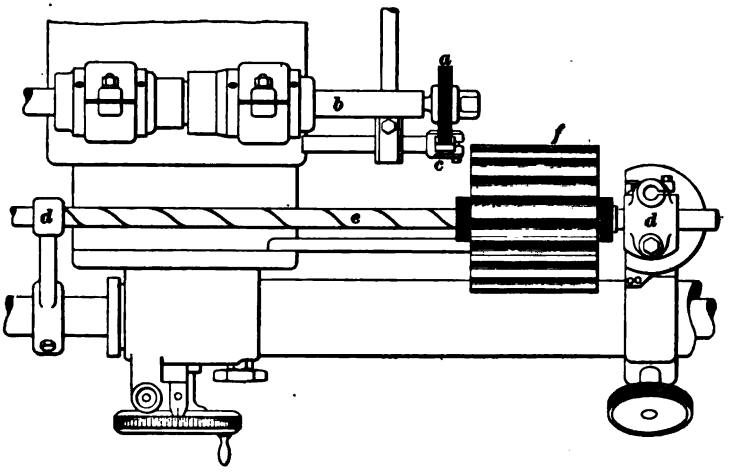


FIG. 24.

within the capacity of the machine. This is done either by making a suitable bar for each size of hole or by making bushings for the larger sizes of holes, so that cutters having large holes may be ground on the small bar. Some cutters and shell reamers have taper holes in them; these must be provided with a bushing having a straight hole fitting the bar, the outside being fitted to the taper hole in the cutter or reamer. When this bushing is in place in the cutter, the latter may be ground the same as any cutter having a straight hole.

99. Form and Position of Guide Finger. — The cutter having been mounted on a suitable bar, the guide

finger *a* is adjusted under one of the teeth, as shown in Fig. 25, so that the grinding wheel is in contact with the back of the land of the tooth. This guide finger should be somewhat wider than the face of the grinding wheel, in order that the cutter may rest on the finger before it

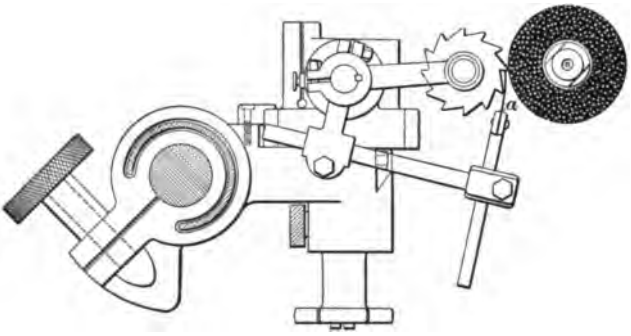


FIG. 25.

reaches and after it leaves the grinding wheel. If the finger is narrower than the face of the wheel, the latter is liable to catch and score the cutter while the latter is engaging or leaving the wheel. The guide finger should always have its top filed so that it is in contact throughout its width with the face of the tooth.

100. Precautions. — Cylindrical cutters, no matter whether their teeth are straight or helical, are ground by moving them past the face of the grinding wheel. The latter should always revolve in such a direction that it tends to press the tooth that is being ground against the guide finger. The teeth are then ground one by one, preferably by light cuts, going several times around the cutter to sharpen it. In order that the cutter may last well, it is essential that the temper should not be drawn from the teeth, or as the shopman expresses it, "the cutting edges must not be burned." Since cutter-grinding machines are not arranged to permit the flooding of the work with water, it follows that overheating can only be prevented by taking light cuts.

101. Cutters ground by sliding them along a cylindrical bar become cylindrical themselves on account of the fact that the distance between the axes of rotation of the grinding wheel and the cutter remains constant at the point where the grinding is taking place, irrespective of whether the two axes are parallel or inclined with respect to each other. The grinding wheel retaining its size, it follows that all points of all teeth of the cutter will be the same distance from its axis; that is, they will be on the surface of a cylinder.

GRINDING SHANK CUTTERS AND ANGULAR CUTTERS.

102. Some cutters, especially those having shanks, cannot be ground on a bar in the manner just described; such cutters are mounted in a suitable socket and ground cylindrical, or to a given angle, by adjusting, by trial, the device in which they are mounted. Angular cutters cannot be ground by sliding them along a bar, and the same device used for shank cutters may be used for them. Thus, the cutter may be mounted on a bar held in a swivel head *a*, Fig. 26, which is set, by trial or by graduations, to the required angle. The guide finger having been adjusted, the cutter is traversed past the face of the grinding wheel by moving the table *b* to which the holding device is attached.

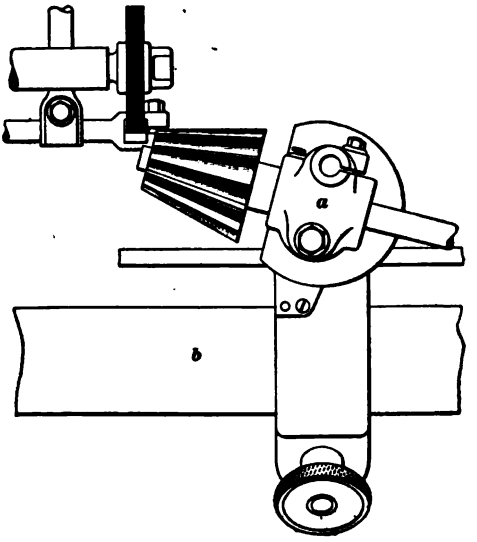


FIG. 26.

REAMER GRINDING.

103. Cylindrical and taper shell reamers may be ground in the same manner as milling cutters, sliding them along a bar if the reamer is cylindrical, and using a holding device if the reamer is tapering. In most cases it will be necessary to make a bushing for cylindrical shell reamers, since they usually have a tapering hole.

104. Reamers that may be classified under the general heading of solid reamers generally have a center at each

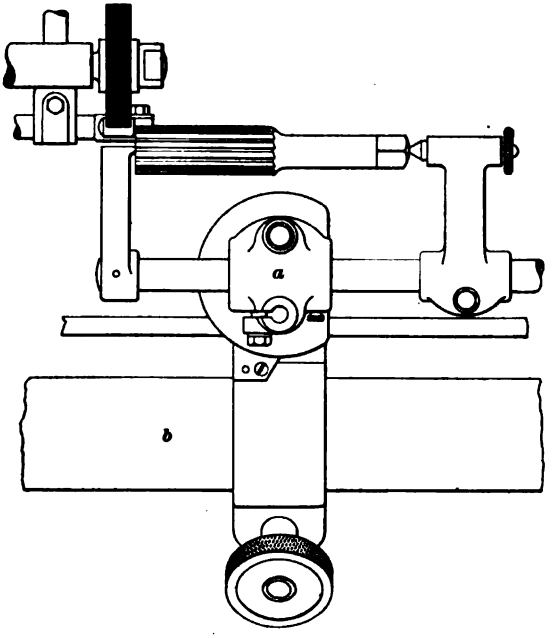


FIG. 27.

end. Such reamers are ground between centers, as is shown in Fig. 27. For grinding cylindrical reamers, the centers are adjusted so that the line joining them, which is also the axis of the reamer, is parallel to the line of motion of the centers; for taper reamers, the axis of the reamer is set at the required angle to the line of motion. In this particular case, the centers are clamped not directly to the table, as in

the cutter grinder that was illustrated in Fig. 23, but to a holding device *a*, which in turn is clamped to the table *b*. The grinding is done by traversing the table *b*, resting the different teeth in succession on the guide finger.

GRINDING TEETH OF SIDE MILLING CUTTERS.

105. For grinding the teeth on the side of side milling cutters, the cutter must be attached to the headstock by means of a suitable socket or arbor, as shown in Fig. 28, where *a* is a holding device or headstock. It will rarely be possible, for want of room, to apply the guide finger to the side tooth that is being ground; in most cases the finger will have to be applied to the periphery of the cutter. It must not be forgotten that the guide finger must be placed in such a position that the pressure of the cut will be against it; this requires the finger to be placed in an opposite position whenever the cutter is reversed after grinding one side. In Fig. 28 this fact is indicated by showing the new position of the finger and the grinding wheel in dotted lines. If the cutting edges of the side teeth are to lie in a plane, the holding device *a* must be swiveled to secure this condition.

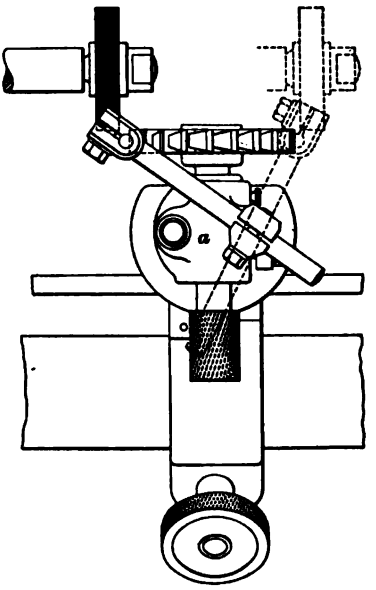


Fig. 28.

USE OF CUP WHEEL.

106. For some kinds of tool grinding and cutter grinding, a cup wheel may be used to advantage. An example showing how the cup wheel is applied is given in Fig. 29,

where an inserted-blade side milling cutter *a* is seen mounted on an arbor held in an adjustable holder *b*. The holder is made adjustable in a vertical direction, in order that the axis of the cutter may be inclined, in respect to the axis of rotation of the grinding wheel *d*, until the desired degree of clearance is obtained. If the guide finger *c* is used on the side of the cutter, as shown, it will be necessary to clamp

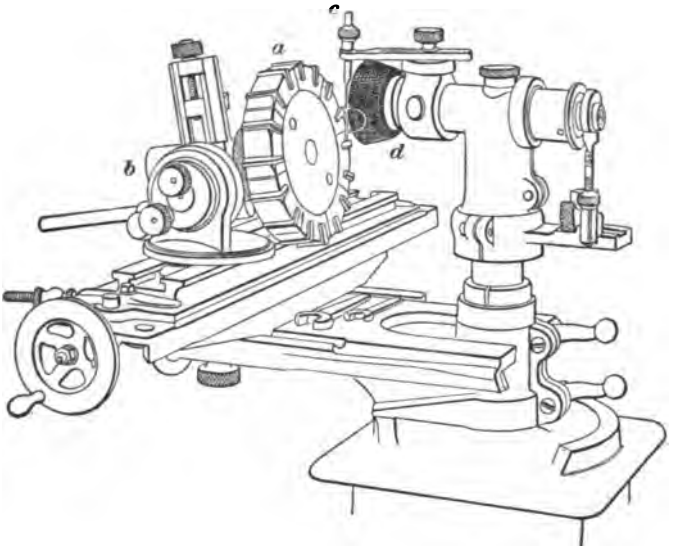


FIG. 29.

the cutter while grinding each tooth as the work passes off from the guide finger or tooth rest before cutting begins. The tooth rest acts as a spring pawl when revolving the cutter. The loop at the back of the tooth rest is for the insertion of the thumb of the operator when it is desired to spring the rest back to clear the teeth. The benefit to be derived from the use of a cup wheel is the well-supported cutting edge that is given to the cutter. The teeth on the side of the cutter can be ground so that their cutting edges lie in a plane, or they can be ground so that their inside corners have a slight relief, by a proper horizontal adjustment of the holder. If the holder can be swiveled sufficiently,

angular cutters may be ground with a cup wheel. The depth of cut is regulated by feeding the cutter toward the wheel, and the grinding is done by traversing the cutter past the wheel.

USING UNIVERSAL GRINDING MACHINE.

107. Introduction.—When no cutter grinder is available, the universal grinding machine may be used for cutter and reamer grinding; and, in many cases, it may also be used for work beyond the range of the cutter grinder.

108. Grinding a Milling Cutter. — Fig. 30 shows how a side milling cutter may have the teeth on its periphery

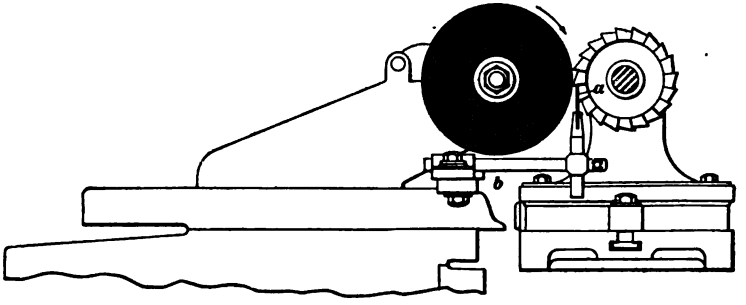


FIG. 30.

sharpened in the universal grinding machine. A guide finger *a* is fastened to a suitable bar *b*. This finger should always be so arranged as to be at rest with respect to the grinding wheel; that is, its position with respect to the grinding wheel should not change. When the guide finger is attached to the wheel base, it occupies a fixed position in front of the wheel, and every part of the tooth that is being ground must travel over it and pass the wheel in exactly the same relative position. This insures that the backing-off is at an angle that is constant throughout the length of each tooth and is the same for all teeth.

109. Mounting Guide Fingers. — Sometimes the guide finger is mounted on the machine table, as shown

in Fig. 31, in which case it travels with the work. This will answer for grinding short work, such as milling cutters less than 1 inch thick and having straight teeth. It is clear that with the guide finger located on the table, it is at rest

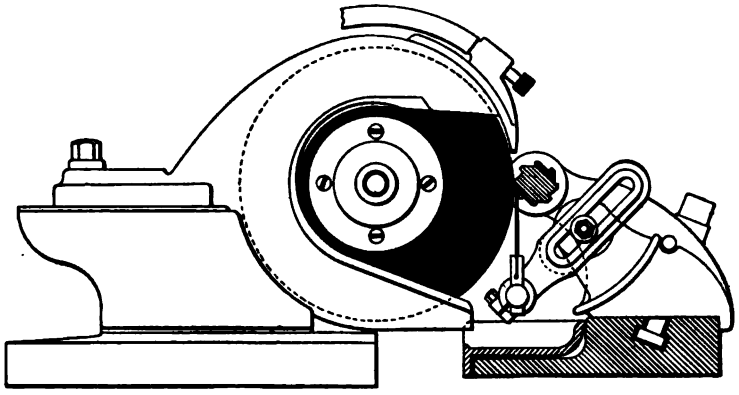


FIG. 31.

with respect to the work throughout the grinding; consequently, it cannot rotate the work, as is absolutely required in the case of tools with helical cutting edges, in order to present every point of each cutting edge to the grinding wheel in exactly the same manner.

110. A beginner is very likely to think that a long cutting tool with straight cutting edges may satisfactorily be ground with the guide finger fixed with respect to the work. This would be the case if there was no warping of the tool in hardening; but after the tool has been hardened, it will be found that no matter how true the grooves were milled, and no matter how carefully the hardening was done, they will have become warped enough to prevent proper sharpening. This can readily be seen if the tool is first ground to run true, grinding it as if it were a cylinder or a cone. Then, adjusting the guide finger so as to keep the backing-off slightly away from the cutting edge and taking the cut, it will be found that the land remaining between the cutting edge and the termination of the backing-off is not equal in width throughout the length of the tooth; this shows that

if the backing-off had been carried clear to the cutting edge, the latter would not be true throughout its length.

111. Location of Guide Finger.—The guide finger should always be so located that the grinding wheel will revolve *toward* it, and should always be placed *between* the axes of the grinding wheel and the work, and just as close to the edge that is being ground as circumstances will permit. It should always be applied to the *face* of the tooth, and never to the back, for the reason that any want of truth of the back will affect the truth of the cutting edge. The mistake of placing the guide finger so that the grinding wheel runs away from it must be guarded against, on account of the liability of spoiling the work caused by the tendency of the wheel to rotate the latter.

DIFFERENT FORMS AND METHODS OF BACKING-OFF.

112. Cutter and reamer teeth are backed off in a variety of ways. For some classes of work and in the absence of the proper facilities for grinding, the tool is turned to the exact size and fluted, after which it is backed off by filing the proper clearance on the teeth. The cutter or tool is then hardened and is perhaps ground by hand on a suitable emery wheel in order to produce a good cutting edge and a clean surface by which to draw the temper. Work done in this manner will prove entirely satisfactory for a large variety of comparatively rough work.

113. Several methods of backing-off are used, each having its special advantage or use, which will be explained together with the manner of the production of each one. The teeth of cutters and reamers are left by the machining process somewhat in the form shown in Fig. 32, which is exaggerated for the sake of clearness. In Fig. 32 (*a*), a section of a tooth is shown in which *a* is the face, and the land *b* is an arc of the circle forming the circumference of the cutter or tool. With the tooth in this shape, it is of little value as a cutting tool, and can do but very poor work until the

land is given proper clearance. The most common form of clearance is shown in Fig. 32 (*b*). An emery wheel is set so as to grind the back *c'* of the land away, and the work and grinding wheel are brought together until the edge *c* is sharp. Obviously, the land will be ground hollow, as shown

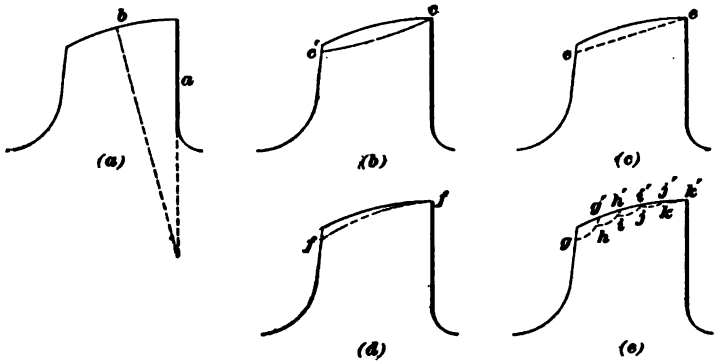


FIG. 32.

by the dotted line *c' c*. In order to leave a well-supported cutting edge, the curvature should be as small as possible; this means that as large an emery wheel as possible should be used. The amount that the edge *c'* is nearer the axis of the tool than the cutting edge *c* is regulated by adjusting the height of the guide finger.

114. A better form of backing-off is the straight backing-off shown in Fig. 32 (*c*) by the dotted line *c e*. This form can be satisfactorily produced only by a cup wheel. Attempts are occasionally made to use an ordinary wheel cutting on its periphery for a straight backing-off, setting the machine so that the axis of the wheel is at right angles to the axis of the tool. Such an attempt will result in unsatisfactory work owing to the wear of the emery wheel, and the method is not to be recommended.

115. It is conceded that the best form of backing-off is as shown in Fig. 32 (*d*) by the dotted line *f f*, which is the arc of a circle. Unfortunately this form of backing-off cannot be produced in the ordinary cutter grinder or

universal grinding machine, but requires a machine somewhat similar to that used for making formed cutters. The advantages of this form of backing-off are a well-supported cutting edge combined with ample clearance.

116. In the absence of a special machine, a fair approximation to the circular backing-off may be given to a reamer as follows: Set the guide finger so low that the wheel will only touch the back of the tooth, grinding it from g to g', Fig. 32 (e), and take this cut over all the teeth. Then slightly raise the guide finger and move the work and wheel apart; now again bring the work toward the wheel until it cuts from h to h'. Continue this cycle of operations until the edge k' is reached. The top of the land will be a succession of ridges that may be smoothed down by careful oilstoning to a very good imitation of the backing-off that a special machine will produce. The method just explained is not recommended for any other cutting tools than reamers. In practice the form of tooth shown in Fig. 32 (b) is generally used.

SHARPENING FORMED CUTTERS.

117. Fig. 33 shows the method of grinding a formed gear-cutter. The cutter is mounted on a stud a in such a manner that the axis of rotation of the grinding wheel b is in the plane midway between the sides of the cutter. A guide finger c is set against the back of the teeth and is so adjusted as to make the face of the teeth radial. The slide on which the stud is carried may be pushed in or out by hand while the table remains stationary.

When formed cutters are ground by hand, a rest is placed in front of the wheel and the cutter laid upon this rest. The cutter is then pushed and pulled back and forth while the face of the tooth is held against the grinding wheel. The rest is often dispensed with in grinding formed cutters; considerable care will then be required to grind the faces of the teeth at right angles to the sides of the cutter. Long

formed cutters may be mounted on a bar and moved back and forth along this bar until the guide finger is in contact

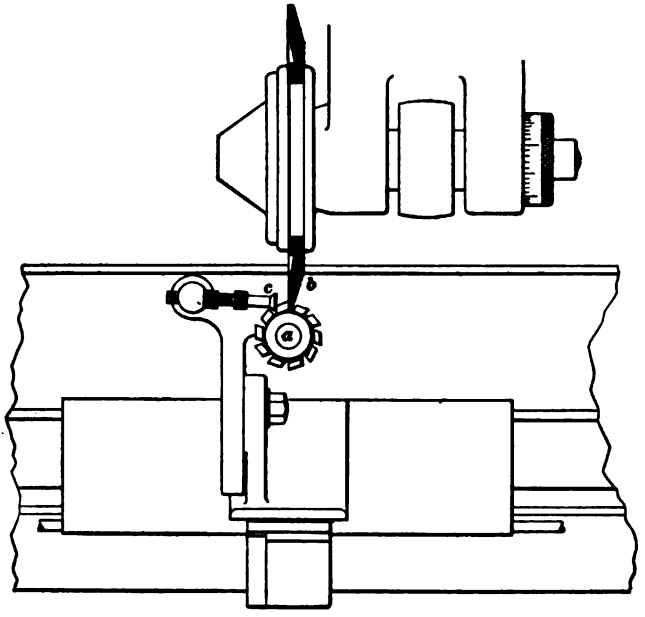


FIG. 33.

with the back of the tooth. The wheel used should be of the dished type; that is, it should be as shown in Fig. 33.

CLEARANCE.

118. Various workmen differ greatly as to the proper clearance for different cutting tools, but the following is probably good average practice. The teeth of milling cutters should be so ground for iron and steel that they will have about 3 degrees clearance. Less clearance is apt to make them drag and cut slowly, and more will make them chatter. Cutters intended for soft metals need a greater clearance. The amount of clearance that the teeth of cutters and reamers should have is easily determined by putting the tool into a ring of corresponding size and looking through

it toward the light. The angle of clearance of any cutter may be found by setting one blade of a universal bevel to the face of the tooth and the other to the clearance; the bevel may then be laid upon a piece of paper and the angle included in the gauge may be extended and measured by any form of protractor.

GRINDING CUTTERS IN PLACE.

119. Large milling cutters are often ground while on their own arbors and in the milling machine, using a special grinding device for the purpose. This is done for two reasons: in the first place, their size prevents them from being ground in a cutter grinder; in the second place, grinding them on their own arbor insures that they will run true.

LAPPING.

THE TOOLS.

DEFINITION AND PURPOSE.

120. **Lapping** is an abrading process in which the abrading material, as emery, is embedded in some soft metal, as cast iron, brass, or lead. It is an extension of the grinding process and is aptly said to be the refinement of grinding. In this process, the results depend largely on the skill of the operator, and bear about the same relation to the finishing of ground work that scraping bears to the final finishing of planed surfaces. The lapping process may be used for finishing the surfaces of unhardened metal where great accuracy is required; it is more frequently used, however, for the final finishing of hardened work.

121. The **tools** used for lapping are quite simple. For lapping holes the simplest lap is made of lead that is cast around an iron or steel arbor, which arbor may be made of

square material, or it may be round and have a groove running lengthwise, in order that the lead will turn with the arbor. A more elaborate form of lap that is intended for cylindrical holes is made of cast iron in the form of a split shell that is placed on a tapering arbor and caused to turn with it by means of a dowel-pin. By driving the shell farther up the arbor, it is slightly expanded. Brass is a very good material of which to construct a lap; it is rather expensive, however. Machinery steel is often used, but it cannot be said to make as good a lap as cast iron or lead on account of the difficulty of embedding the grinding material in it.

USING A LAP.

122. Internal Lapping. — In use, a lap is charged with emery and oil and is then rapidly passed back and forth across the work, or vice versa. If the lap is intended for a cylindrical hole, it must obviously be slightly smaller than the hole in order that it may enter when charged with emery, but if a true hole is desired, the lap must be as large as can be worked in the hole. For finishing laps on fine work no allowance is made for the cutting material when making the lap. When a lap ceases to cut, it must be expanded or a new one made. When the lap is made of lead, it can often be expanded by driving the arbor home a little, holding the lap in one hand. The lead, being soft, will stretch quite easily. It will be found, however, that after a lead lap has been expanded two or three times in this manner, its surface will be uneven; a new lap must then be made. It will be understood that the work or the lap must rotate at a fairly high speed during the lapping process. While the lapping can be done in a grinding machine, it is usually more convenient to use a hand lathe.

123. Grade of Emery.—The grade of emery that is to be used depends on the amount of stock that is to be removed and the degree of finish that is desired. Thus, for the finest finish, like that given to cylindrical standard

gauges, the very finest of flour emery must be used; if the lapping process is used to rough down a piece of work because no grinding machine is available, a coarse grade of emery may be used. In order that the lap may work well, it is essential to supply it with plenty of oil.

124. Lapping a Conical Hole.—A conical hole is rather difficult to lap smooth, because the lap cannot be drawn back and forth across the surface. Because of this fact, the lap is very liable to cut concentric ridges into the work; furthermore, the grinding material is likely to creep toward the larger end of the lap, by reason of the action of the centrifugal force due to the rapid rotation of the lap. This will cause the lap to grind the hole to a different taper than that given to the lap; but this tendency can be counteracted somewhat by cutting into the lap a spiral groove having a direction of rotation opposite to that of the lap. Thus, if the taper lap shown in Fig. 34 (*a*) turns in the

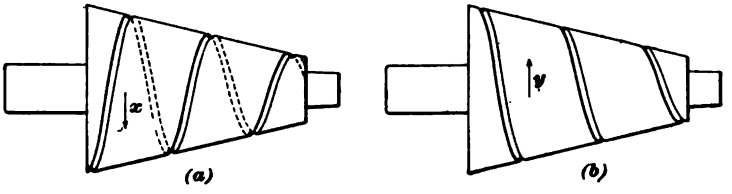


FIG. 34.

direction of the arrow *x*, the groove should be left-handed, but if it turns as shown by the arrow *y* in Fig. 34 (*b*), the groove should be right-handed. Several laps will have to be used to lap the hole smooth and especial attention must be paid to the prevention of glazing. In lapping conical holes, much finer emery should be used than for cylindrical lapping.

125. External Lapping.—An external lap is usually made in the form of a ring that is lined with lead, brass, or cast iron. The length of the lap should be not less than 1 diameter for a cylinder, and can profitably be more. The ring may be split and a screw provided for closing in

the lap when it has become so worn that it will not cut. When much external lapping is to be done, the ring may be provided with a handle about 15 inches long for the sake of convenience in using it.

126. Lapping Odd Shapes.—Odd shapes are sometimes lapped to bring them to the required degree of truth and finish. Work having an odd shape is made as nearly perfect as possible by machining; a lap is then made by casting lead on the part to be finished. Laps of this kind cannot be moved back and forth to prevent their cutting rings into the work. For this reason the same precautions should be taken that were mentioned in connection with laps for taper work.

127. Lapping Holes of Milling Cutters.—While the hole of a solid milling cutter can best be finished by grinding it in a regular grinding machine, there are many places where, on account of the absence of such a machine, grinding is impossible. Lapping may then be used. A lap that is small enough to enter the hole is placed between the centers of a hand lathe and, after coating the lap with oil and emery, the cutter is placed on it. It is not advisable to attempt to hold the cutter with the bare hand on account of the danger of an accident; a strip of pine board may be used to advantage in rotating the cutter, using it in the same manner as you would a file. While the lap is rotating, the cutter should be moved back and forth from one end of the lap to the other until the lap ceases to cut. A new lap is then made or the old one expanded, and the lapping continued until the hole is of the correct size.

128. Lapping Valve Seats of Piston Valves.—The valve seats for the piston valves used in some makes of steam engines for the distribution of the steam must be truly cylindrical and very smooth in order that the leakage of steam and the wear may be reduced to the lowest limit. In some cases these seats are finished by first grinding or reaming them when they are in place in the steam chest, and then lapping them in order to obtain a very

fine and smooth surface. The lap may be made of any suitable material; after being charged with flour emery it is pushed back and forth through the valve seats, being rotated alternately to the right and left, until it ceases to cut. A slightly larger lap is then introduced, and the operation of lapping is repeated until the seats are truly cylindrical and smooth. It is essential that the lap itself should be as nearly cylindrical as it can be made. The number of laps that will be required for each pair of valve seats depends on the condition and alinement of the two seats.

129. Lapping Plane Surfaces. — The lap may be made of any suitable material, though cast iron is thought to be the most satisfactory. The face of the lap is planed as true as possible and covered with oil and emery, after which the work is rubbed over it, changing the work around frequently and rubbing it in all directions. Great care is required to prevent crowning the work, that is, lapping the edges away faster than the center. The lap must be planed off frequently, as it wears out of true quite rapidly.

130. When the work is of such a nature that it is easily tipped by being moved about, it should be placed in a holder of some kind that will prevent this. Thus, suppose that the rectangular bar shown in Fig. 35 (*a*) is to be lapped on the ends so that they are at right angles to the surfaces *a* and *b*, and, consequently, parallel. A block may then be made with a V groove planed in one surface at right angles to the bottom surface, as shown in Fig. 35 (*b*). The work is placed into this groove, and, if small, may be held there by having a few rubber bands placed over it. The holder and the work are then rubbed over the lap. It

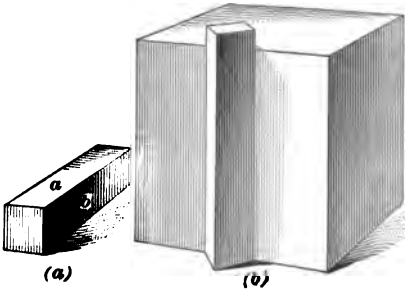


FIG. 35.

is seen that the holder insures the lapping of the ends of the work at the proper angle, and at the same time prevents the work from being tipped.

131. Lapping Circular Arcs.—It is sometimes necessary to lap an arc of a circle to an exact radius. This can be done by a cylindrical lap having a corresponding diameter. The lap may be held between the centers of a lathe, where it is driven by a dog. An angle plate may then be clamped to the slide rest, and the work may either be held by hand or be clamped against the angle plate. While the work is pressed against the revolving lap, the slide rest is moved rapidly back and forth. The action of the lap in this case may be likened to that of an emery wheel grinding a concave surface into the end of a piece that is held stationary on the rest of a grinding machine.

132. Lapping Diamond Tools.—While the use of diamonds for taking light finishing cuts on metals, both in turning and boring, is not general, there are still quite a number of shops in which diamond tools are used for finishing duplicate work. The diamond is used chiefly because its hardness prevents a rapid wear; then, as the expense of sharpening tools is thus greatly reduced, it will be found that on many classes of light work the diamond tool, in spite of its great first cost, will prove much more economical than steel tools. Diamond tools are not adapted for heavy cuts, being too brittle to stand much pressure; they answer admirably, however, for very light finishing cuts, and as they hold their edge well and permit a much greater cutting speed to be used than will a steel tool, they tend to increase the output of the machine.

133. For this work the **black diamond** and the **bort** are the kinds usually used, though sometimes white diamonds are used. The stone is set into a hole drilled in an iron or steel holder, and is lightly held by peening the metal toward the stone. The holder, with the diamond on top, is then sometimes put into a fire and the stone is securely brazed in, leaving but a small part projecting from

the holder. In other cases the diamond is fastened without brazing, the metal being carefully peened about the stone. After the surplus metal has been filed away, a proper cutting edge is ground on the diamond. For this purpose a cast-iron or machinery-steel wheel about $\frac{3}{16}$ inch wide and 6 inches diameter, running about 1,000 revolutions per minute, is used. The periphery of this wheel is charged with diamond dust, which is either rolled in with a small roller or hammered in with a small hammer. The grinding, or lapping, as many call it, is then done by using the wheel in the same manner as an emery wheel is used, the diamond being lightly held against the wheel. Owing to the hardness of the diamond, the process of lapping it to the required shape is naturally a slow one.

BENCH, VISE, AND FLOOR WORK.

(PART 1.)

INTRODUCTION.

1. The machine-shop operations previously considered have been almost entirely associated with machine tools. Aside from these, there is a large amount of work done by hand, such as laying out, chipping, filing, scraping, fitting, etc. These operations are usually performed either on a bench or on the floor, depending on the size or weight of the work; hence, the name *bench, vise, and floor work.*

Bench work is of a lighter nature than floor work, though it may, and often does, include the entire finishing and erecting process where the machine is small, and in the case of large work many of the small parts are assembled at the bench and are then taken to the floor and adjusted to the other parts.

Floor work includes the erecting and assembling of heavy machines and the machining of parts too heavy or too large to be operated on in the stationary machine tools. In the latter case the heavy parts are set up at a convenient place on the floor and the machining done by means of portable tools set up at a suitable location for each operation. Under this heading the tools and processes employed will be considered, as well as the work itself.

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BENCH AND VISE WORK.

TOOLS AND FIXTURES EMPLOYED.

TOOLS.

2. Hammers.—Machine-shop practice calls for a variety of operations that may be classed as **hammering.** A blow struck may be only the fraction of an ounce, such as a tool-maker strikes on his prick punch in laying out accurate centers, or it may be a blow delivered by a ram weighing a half ton and pushed by a dozen men. The hammers used by machinists weigh from ¼ to 2 pounds, and are designated as **ball-peen, straight-peen,** and **cross-peen.** The one most commonly used is the ball-peen hammer, weighing from 1 to 1¾ pounds; it is shown in Fig. 1 (*a*). This hammer is used for all ordinary work, including riveting, and the effect of the blow struck by the ball is equal in all directions. The straight-peen, Fig. 1 (*b*), and cross-peen, Fig. 1 (*c*), are used when the effect of the blow must be greater one way than the other. The smallest sizes of hammers are used on light work, such as prick marking and finishing on dies.

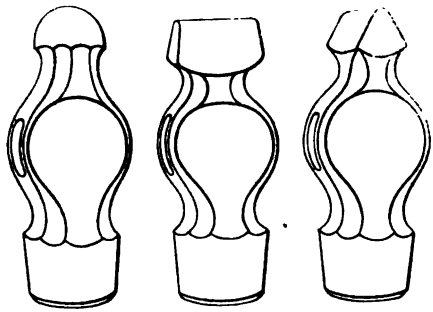


FIG. 1.

3. Center and Prick Punches.—Center punches, which are illustrated in Fig. 2 (*a*), are used, as their names indicate, for punching the centers of holes to be drilled in the ends of shafts and similar pieces that are to be turned in the lathe, and also for making a mark or hole for starting a drill in any drilling work.

The prick punch shown in Fig. 2 (*b*) is similar to the center punch, but may be smaller, and must have a sharp, well-ground point. The prick punch is only used to make

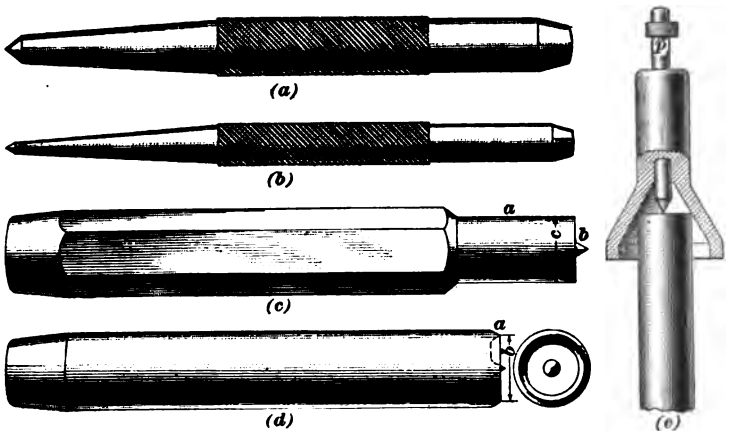


FIG. 2.

the light marks in laying out work, while the center punch is used to make a larger hole and often to move a center hole one way or another. Center punches should be ground to an angle of 60°.

4. The Marker.—The marker shown in Fig. 2 (*c*) is a center punch made of octagon steel; the part *a* is turned to the size of the holes to be marked off, and the center *b* projects about $\frac{1}{8}$ inch. In boiler work, rows of holes are first punched in the edges of the plates, which are then bolted in place; the circular part *a* of the marker is put through the holes in the first sheet and a blow struck on the head drives the point *b* into the under sheet, thus making a mark for the center of the punch. When all the holes are marked off, the sheet goes to the machine and the holes are made as marked. The size *c* of the marking punch must in all cases be the same as that of the punched hole. The marker is a tool that is also used in the machine shop to some extent.

Holes that are laid out for drilling have a circle drawn to their diameter with a pair of dividers. Where large numbers of these are to be drawn, a tool like that shown in Fig. 2 (*d*) is useful. This may be made from a piece of round steel turned as shown at *a*, making a center punch surrounded by a sharp ring *b*. The point of this tool is placed in the prick-punch mark that shows the center of the hole, and a blow on the head of the tool locates the circle. In some cases, the diameter *b* of the tool is made the same as the diameter of the hole to be drilled, though for some work it is made larger than the hole and shows whether the work has been properly drilled.

The cup center, Fig. 2 (*e*), may be conveniently used on work having true ends.

5. The Scriber.—The scriber, which is usually made in the form shown in Fig. 3 (*a*), is commonly made of a piece

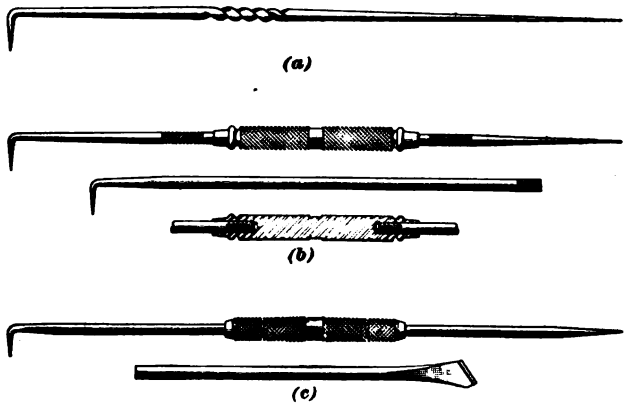


FIG. 3.

of $\frac{3}{16}$-inch steel wire, from 6 to 10 inches long, ground sharp on both ends, twisted in the middle so as to be easily held in the hand, and with one end bent at right angles to the main part. It is hardened and tempered so that it will scratch

any metal but hardened steel, and it is used for drawing lines in laying out work; it may be called the *machinist's pencil.* Improved scribers, Fig. 3 (*b*) and (*c*), with nurled handles and inserted scribing points of fine quality, are made by tool manufacturers, and may be bought at reasonable prices. The first of these has a solid handle into which the points are screwed; the second has a hollow handle with a screw chuck at each end, which is slipped over single- or double-pointed markers and clamped wherever desired.

6. Bench Centers.—The bench centers illustrated in Fig. 4 are for the convenience of the viseman in centering work for the lathe. The centers *a* and *b* may be set at any location along the rod *c*. The head *d* is provided with either a spring or a screw center, so that the piece can easily be put in place or removed.

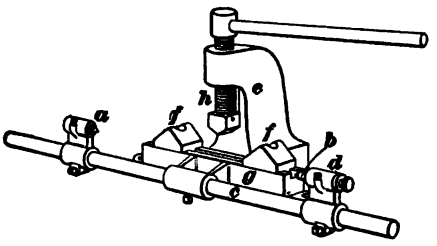


FIG. 4.

The operator takes the piece to be centered, puts it in the vise, and center-punches it as nearly as possible in the center. He now puts it in the bench center and rotates it, noting whether it runs out, and how much. Having found which side is out of the center by marking with chalk, he proceeds to draw the center hole over toward that side with the center punch. This operation must be repeated until the piece runs true enough to finish. If the middle of the piece is out of true or is crooked, it should be straightened by hammering or by bending in the screw-straightening press *e*, back of the centers. The straightening press consists of two movable V blocks *f*, *f* resting on a base *g*, and a screw *h* with a V point on the lower end, the screw being supported in a frame, as shown. To straighten a piece, it is laid upon the blocks *f*, *f*, with the bend up, and the screw lowered until the bend is removed.

7. Hand Hack Saws.—The hack saw is a tool of growing importance in the machine shop, as well as in many other places. These tools were formerly rarely met with, as they were high in price and much labor was required to keep them filed sharp enough to be of any great service. Hack-saw blades are now made in lengths of from 6 to 16 inches and even longer, and may be used either in hand frames or in specially designed power machines.

The hand frame illustrated in Fig. 5 (*a*) is an adjustable frame in which blades from 8 to 12 inches long can be used. The clamps holding the blade may be set in four positions, which allow the saw to be operated in any direction. Fig. 5 (*b*) shows the blade set at right angles to the plane of the frame to cut lengthwise of the piece.

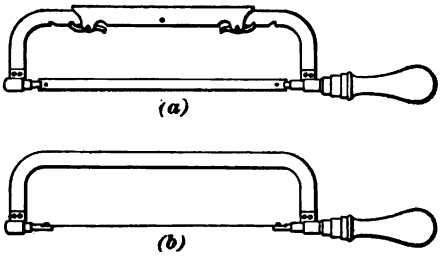


FIG. 5.

8. Power Hack Saw.—The power hack saw illustrated in Fig. 6 in many instances takes the place of the cutting-off lathe. These machines are provided with a vise for holding the stock to be cut off, and are made to stop when the piece is cut through. The blades used in the machine are generally 12 or more inches long; they will cut stock as large as 4 inches in diameter, and will cut any metal not hardened or tempered. The power saw has a great advantage over the cutting-off machine, in that it will cut stock of any irregular section. It is especially adapted to cutting off tool steel, which it does quickly, with very slight waste. The saw frame of this machine has an upward motion during the back stroke that lifts the teeth off the piece being sawed, thus saving the points of the teeth.

Hack-saw blades are so hard that they cannot be filed, and so cheap that when dull they may be thrown away. They

are made with about 25 teeth per inch for sawing thin metal, brass tubing, and pipe, and with about 14 teeth per inch for other work. The blades used in hand frames are about $\frac{25}{100}$ inch thick and $\frac{1}{2}$ inch wide, an 8- or 10-inch blade being the most economical. Longer blades can be used in the power-driven hack saw than in the hand hack saw, on account of the fact that in the power machine the blade is guided uniformly in a straight line, while in the hand hack saw the

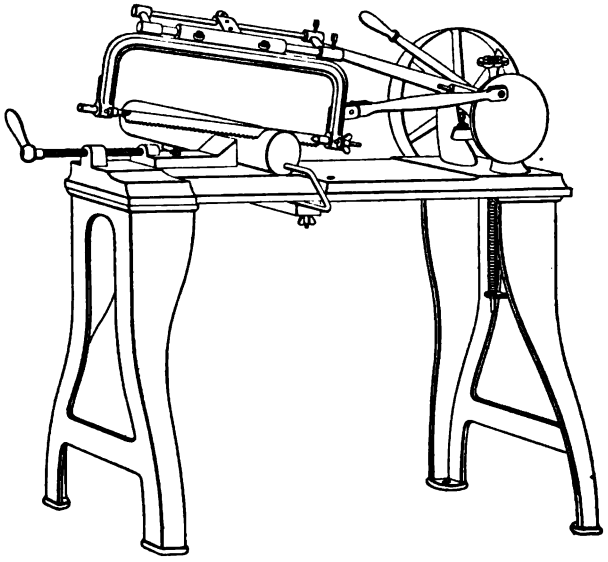


FIG. 6.

blade is liable to run unevenly, and so to become cramped and broken. The blade best suited to the machine has about 12 teeth to the inch, is about $\frac{3}{100}$ inch thick, and $\frac{5}{8}$ inch wide.

Hack-saw blades, while very hard, have a fair amount of elasticity; 10-inch blades of the best makes may be bent to a half circle without breaking. In hand work, the operator should lift the frame up slightly when drawing the saw back, as the back stroke is more destructive to the teeth than the forward stroke.

CLAMPING AND HOLDING DEVICES.

9. Introduction. — In the machine shop a large amount of work is necessarily done by hand, and holding and clamping devices of various sorts are required for pieces that are not heavy enough so that their own weight will give them the necessary stability. The parallel jaw vise will hold nearly all plane pieces, and special jaws or devices are made for holding irregular and special forms. Several types of vises and special devices will be illustrated and described, and these may serve to suggest others suitable for special operations.

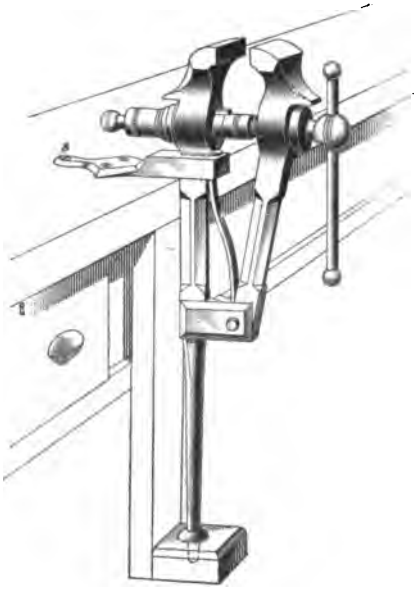


FIG. 7.

10. Screw Vise.— In Fig. 7 is illustrated a heavy form of ironworker's vise designed for the largest, heaviest, and roughest class of work. The jaws are made as large as 8 inches wide; and while this type is useful for large work, it is also copied in the well-known hand vise with jaws 1 inch or less in width. In this vise the jaw is operated by the screw, which requires considerable time for its manipulation. Where a vise has to be operated frequently or through a considerable portion of its jaw traverse, some special provision must be made.

11. Rapid-Motion Vise.—In Fig. 8 is an illustration of a vise so constructed that the operator simply pushes the

cam-handle *a* away from him with his right hand, and thus releases the work and allows the movable jaw *b* to be rapidly pushed or pulled into any position. The work is placed between the jaws and gripped by a pull on the lever.

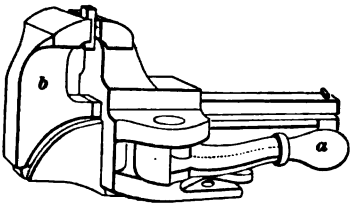


FIG. 8.

12. Swivel Vise.—For the tool room and many places where light or fine work is done, a screw vise like that shown in Fig. 9 is frequently used. This vise is made in various sizes up to those with 7-inch jaws. A common size for tool-room use has a jaw $2\frac{5}{8}$ inches wide. The back jaw *a* is hinged and held parallel with the front jaw by a taper pin *b*, as shown. It is often desired to hold wedge-shaped pieces, and for this work the pin *b* is removed and the pressure of the fixed jaw against the work rotates the movable jaw to conform to the piece held. This vise is also provided with a base plate *c*, which is bolted fast to the bench. The vise proper is swiveled to this base and held in any desired position by the pin *d*, which is drawn up to release the vise and dropped into one of a series of holes in the base when the vise is in the proper position.

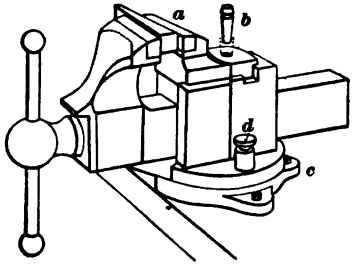


FIG. 9.

13. Pipe Vise.—The pipe vise is a special form of tool made for firmly gripping pipe or other hollow pieces that would be crushed if gripped in the ordinary vise. Fig. 10 illustrates one of the best forms of vise for this class of work. The pipe is gripped between two jaws *a*, *a'* held in a malleable iron frame with a movable top *d* hinged at *e*.

When in use, the free side of the top *d* is held in place by the pin *f*. The hinged top on this vise allows fittings to be screwed to both ends of a piece of pipe, and then, by simply withdrawing the pin *f*, the whole top of the vise may be thrown back clear of the work, which can be lifted out instead of being pulled through the jaws.

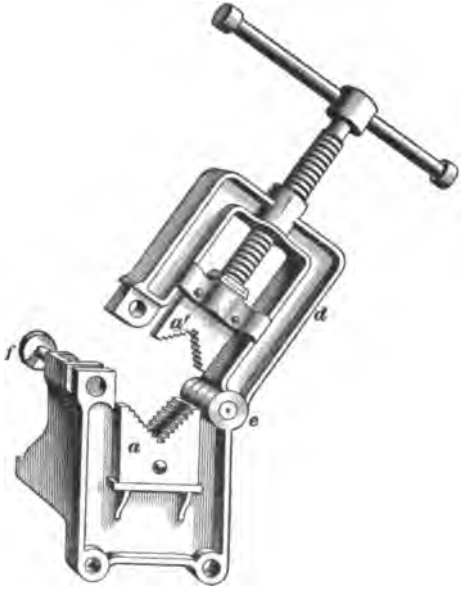


FIG. 10.

14. Vise Jaws. All the vises illustrated are made of cast iron, except the pipe vise, which is of malleable iron. These materials make poor gripping surfaces, so the jaws are covered with welded or riveted steel faces having cross-cuts on them, in order to grip the work more firmly. It is plain that a piece of finished work gripped in such a manner would be seriously marred. This trouble may be overcome by using the device shown in Fig. 11, which is admirably suited for holding the best finished work. It consists of two pieces *a*, *a* having shoulders *b*, *b* to keep them from falling out of the vise. These pieces are held apart by springs *c* that press them against the jaws when the vise is open, and they are faced with vulcanized paper,

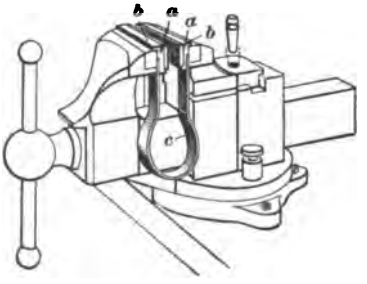


FIG. 11.

which is used like any of the copper, lead, or leather pieces so commonly used for such work. An appliance of this sort provided with round holes of various sizes, half of the hole being in each jaw, permits finely polished brass or nickeled pipe and similar work to be held without marring the finish.

15. Special Forms of Vises.—Special forms of vises are often made for holding work of such form as is inconvenient to hold in the common vise. A good example of this class of tool is the **filing stand** shown in Fig. 12 (*a*), which is a fixture for holding the swivel slide of a planer head while the edges are being finished. This vise, or holder, consists of a three-legged base *a*, screwed to the floor, supporting an upright *c* that may be clamped in any position by the set-screw *b*. The top of the upright is bent at right angles to *c* and threaded for the nut *d*, which clamps the work *e* against the solid collar *f*, as shown in the detail view of Fig. 12 (*b*).

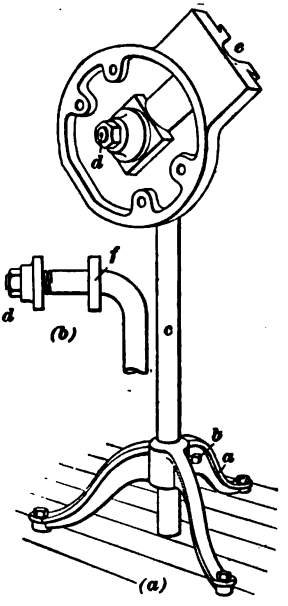


FIG. 12.

16. The **reaming stand,** Fig. 13, is another form of special vise, consisting of an upright *a*, the top *b* of which carries four jaws *c* operated by the handle *d*. This stand is bolted to the floor and has an opening *e* in the column, so that tools may be run clear through the work and removed at the bottom. Pulleys, gears, and similar pieces may be held for hand reaming, and work may also be held for tapping. A similar and, for some purposes, more convenient form of reaming stand is made by fastening a four-jaw combination or universal chuck on an upright.

The universal chuck has the advantage in that for many small pieces only one screw has to be moved to put in or remove the work.

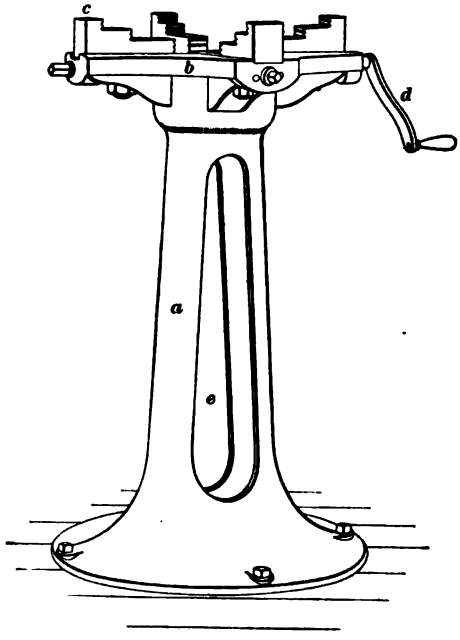


FIG. 13.

BENCHES.

17. Introduction.—It has already been said that bench work is to be distinguished from floor work only by the size and weight of the parts on which the work is to be done, the heavier parts being placed on the floor and the lighter on benches of suitable height. The benches form a very important part of the equipment of a shop, especially where a large amount of light work is done. They are usually made about 30 to 36 inches high, depending on the character of the work, the lighter work being done on the higher benches.

The design of benches varies greatly, some being made stationary and others portable. The design must, however, always have provision for attaching a vise, without which a machinist's work bench is not complete. For this reason they are frequently called *vise benches.* A number of representative benches of the best classes in use are here described.

18. General Arrangement.—The vise bench should be located along the side of the room where the best light is

to be had. The north side of the building makes the best location for the bench, because the light is more even at all hours of the day. The main features of the bench must, of course, be governed by the work to be done, but it should always be convenient, clean, and rigid. In many shops the bench is made with wooden uprights fastened to both the wall and the floor, and a hardwood top, which is 2 inches thick for a bench for light work, and from 3 to 4 inches thick for a bench for heavy work. The front of the bench gets the hardest usage, and the back half of the top may be made much thinner. Vises suitable for the work to be done should be located at convenient distances apart, and for each vise there should be one or more drawers, each provided with a lock and arranged to hold conveniently such tools as the workman may require. Sometimes a tier of drawers is put in instead of the single one, while at other times cupboards are preferred. Cupboards, however, take up a great deal of room and hold comparatively little, and for this reason the drawers are usually more desirable.

19. Bench With Cast-Iron Legs and Frame.—The best form of bench for general use is that illustrated in Fig. 14. A cast support *a* is bolted to the floor and also to the wall. The lower part has a bracket for carrying a shelf *b* that extends the whole length of the bench, while provision is made under the top for alternate drawers and shelves. Provision is also made in each support by which the bolt holding the vise passes through the casting and thus holds the vise in the most rigid position. The shelf near the bottom is so placed as to allow ample room for the sweeper to get his broom clear to the wall. The top of the bench should be made smooth, and all the visible woodwork should be varnished with good shellac. This makes it much easier to keep neat and clean. If the shop is heated by steam, the pipes may be placed under the bench and openings *c* provided before the windows. This insures a rising current of warm air past the window and so protects the

workman from cold drafts. In the form shown, a gas pipe *d* extends along the back of the bench.

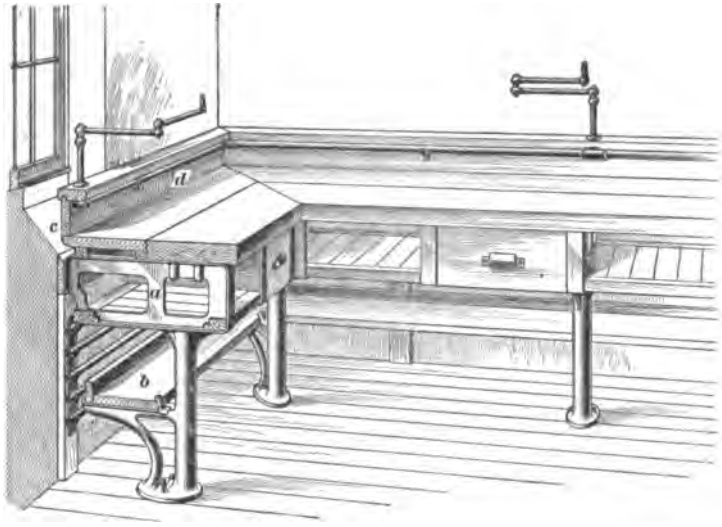


FIG. 14.

20. Portable Benches.—Another form of bench is the portable bench, of which Figs. 15 and 16 are good types. The larger of these, Fig. 15, is made with an angle-iron frame *a* carrying a wooden shelf *b* and having a cast-iron top *d* that may be planed true and used as a laying-out table. It is provided with two vises and drawers *c*, *c*, for tools. This bench may be moved to the work, instead of taking the work to the bench, which makes it especially useful in large shops where heavy machinery is erected; and when engines or other machines are shipped, the bench is often loaded on the cars as one of the erecting tools, and is returned to the shop when the work is finished.

The bench illustrated in Fig. 16 consists of a cast-iron

column *a* carrying a cast-iron top *b* provided with two vises,

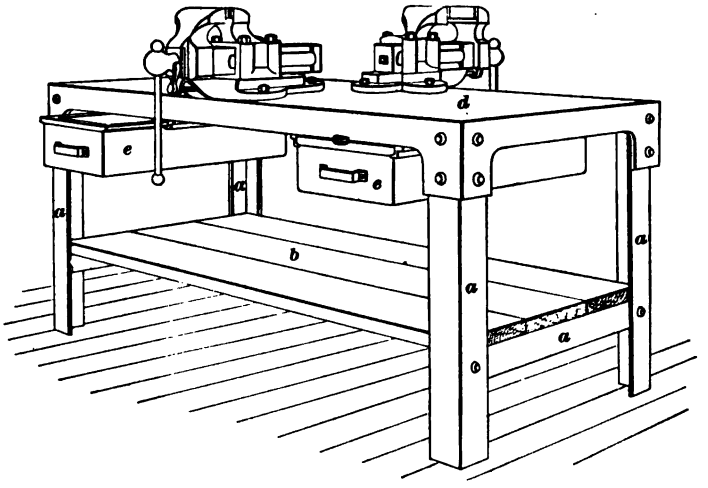


FIG. 15.

but the bench may be used without the vises for a small laying-out table. A cast drawer *c* held by gibs *d* provides

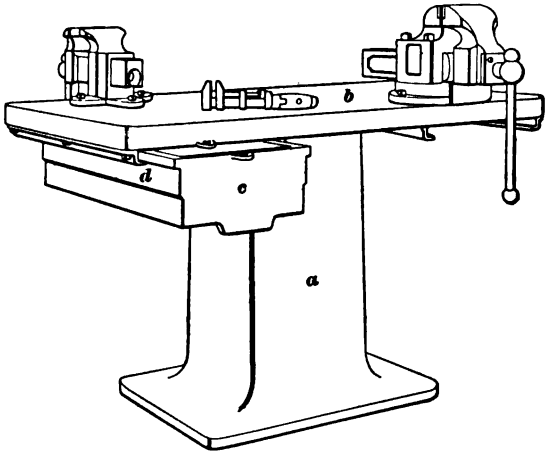


FIG. 16.

a convenient place for the tools used by the workman. This

bench is easily moved to any part of the shop where the work is being done, and it takes up but little space.

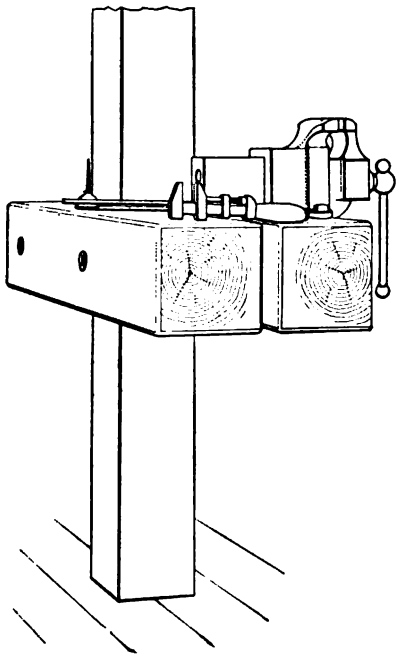


FIG. 17.

21. Post Bench.— Fig. 17 shows a convenient form of bench that may easily be constructed out of two pieces of timber cut to fit a post or column and fastened in position with two bolts. It is useful principally as a vise bench, as shown, but may be used for a variety of purposes.

COLD CHISELS.

22. Flat Chisel.— The forms of chisels most commonly used are the *flat*, *cape*, *diamond*, *grooving*, and *side* chisels, and the *gouge*. They are generally made from octagon steel of such size as to be most convenient for the work for which they are to be used. Special grades of steel are made for chisels, and much trouble will be saved by using these grades for this class of work.

The **flat chisel** is the one most generally used; it is made in the form shown in Fig. 18 (*a*) and (*b*). The width of the cutting edge should, if possible, be proportioned to the hardness of the metal on which it is to be used; but if one width of chisel must answer for brass, cast iron, steel, and Babbitt, lighter blows should be struck while cutting the softer metals, or the metal will be broken away before the chisel and not be cut smoothly. A chisel about 1 inch in width is ordinarily used for general purposes.

For finishing surfaces, the edge of the flat chisel should be ground square, as shown in Fig. 18 (*a*), the best angle for ordinary work being about 60°, as shown in Fig. 18 (*b*). This angle may, however, vary between about 50° and 75°, depending on the hardness of the material to be chipped.

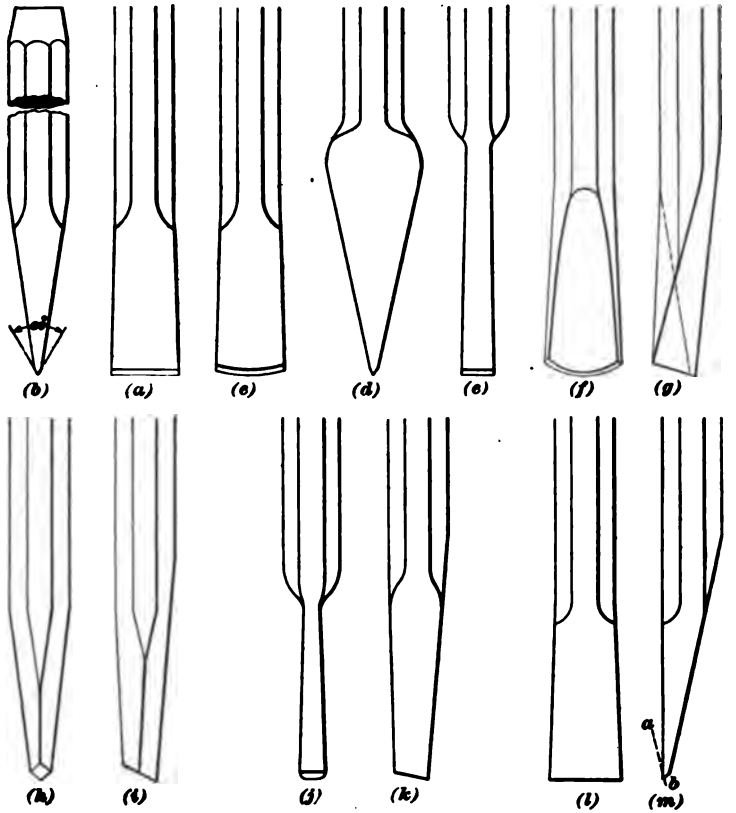


FIG. 18.

Chisels ground with square corners, as shown in Fig. 18 (*a*), are apt to have the corners broken when used for heavy work, but this can be prevented to some extent by grinding the chisel slightly rounding, as shown in Fig. 18 (*c*). This mode of grinding is especially useful for chisels that are to

be used for removing small amounts of material from fine work, as the corners are always in sight and serve as guides to the operator.

23. Cape Chisel.—The cape chisel, which is shown in Fig. 18 (*d*) and (*e*), is used for narrow grooves, and is made in widths to correspond to the widths of the grooves to be cut; for general work it may be from $\frac{3}{8}$ to $\frac{1}{2}$ inch wide. This chisel should be made wider at the cutting edge than it is farther back, in order to provide side clearance. The chisel will then work easier and will not break out the edges of the groove. Where a large surface is to be finished by chipping, it is customary to drive a number of grooves across it with the cape chisel and then use a flat chisel to remove the stock left between the grooves.

24. Gouge.—The half-round gouge shown in Fig. 18 (*f*) and (*g*) is for work on rounded surfaces or fillets, or for cutting half-round grooves.

25. Diamond Point.—The diamond point shown in Fig. 18 (*h*) and (*i*) is used for V-shaped grooves or for finishing out corners. It is largely used with a very light hammer in lettering bottle molds, for which use it is made of $\frac{3}{8}$-inch steel.

26. Grooving Chisel.—The grooving chisel, Fig. 18 (*j*) and (*k*), is used for oil grooves and similar work, and is often made of extra length to reach through long hubs. This chisel should be made wider at its cutting edge than it is farther back, as in the case of the cape chisel; otherwise it is apt to leave a burr on the edges of the groove.

27. Side Chisel.—The side chisel, shown in Fig. 18 (*l*) and (*m*), is used for finishing the sides of slots and similar work. The chisel is ground straight on the side next to the work, if it is to be used in deep holes; for shallow holes it is best to give it a slight angle, as indicated by the line *a b*, Fig. 18 (*m*), and to allow the body of the chisel to stand at a greater angle to the work while being used.

The proper cutting angle for most of the chisels mentioned above is practically the same as that for the flat chisel for metals of the same grade, the angles for different grades of metal varying from 50° to 75°. The softer the metal, the sharper the chisel should be.

Cold chisels are often used in the pneumatic hammer, and when so used the shanks must be fitted to the holder in the hammer, either by turning or milling, and the head should be carefully tempered in order to keep it from being upset in the socket of the machine. The chisels used in the pneumatic machine should be longer than those used by hand.

CHIPPING.

28. Introduction.—Chipping is the process of removing stock by means of the hammer and chisel. It corresponds to the roughing cut in machine tool work, and the filing that follows it takes the place of the finishing cut.

There are two methods of chipping—the hand and the pneumatic. Chipping is a process applied to the roughest and coarsest work, and it is also used on some of the finest work that comes to the machinist. It is used in the machine shop, foundry, and smith shop, and chisels of various sorts form an important part of the outfit of the erecting gang. A heavy chisel fitted with a wooden handle is used in both foundry and machine shop, for removing the largest projections and fins on castings.

29. Holding the Hammer and Chisel.—For ordinary chipping, a hammer weighing from 1 to 1¾ pounds is used, and a variety of chisels, the most common of which are the flat, cape, gouge, and various forms of side and grooving chisels. When chipping, the hammer is held in the right hand, as shown in Fig. 19, and is grasped by the thumb and second and third fingers, the first and fourth fingers being closed loosely around it. This method of holding the hammer handle allows it to be swung more steadily and more freely without tiring the hand so much as

would be the case if the handle were grasped rigidly by all four fingers. The chisel should be grasped in the left hand with the head close to the thumb and first finger. The chisel is held firmly with the second and the third fingers, and the little finger may be used to guide the tool as may be required. The first finger and the thumb should be left slack, as they are then in a state of rest, with the muscles

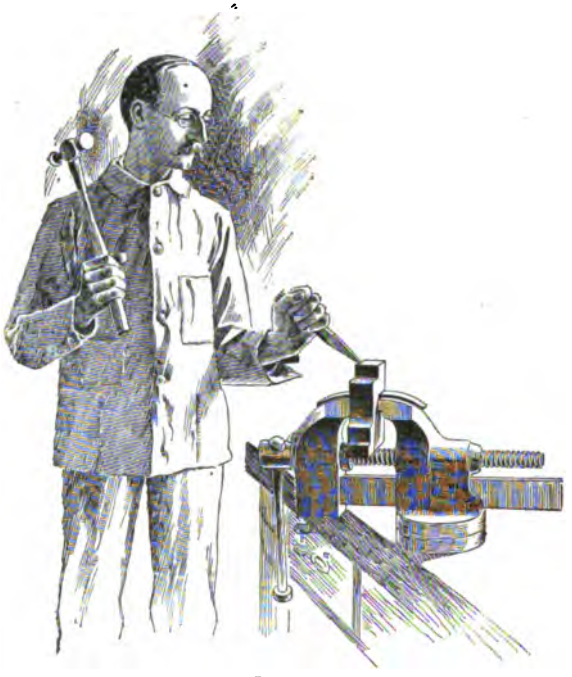


FIG. 19.

relaxed, and are less liable to be injured if struck with the hammer than if they were closed rigidly about the chisel. The point of the chisel is held on the work, as shown in Fig. 19, at the place where it is desired to take the cut, before the hammer blow is delivered, and at an angle that will cause the cutting edge to follow approximately the desired finished surface. After each blow the chisel is reset to its proper position.

EXAMPLES OF CHIPPING.

30. Piston-Valve Bushing.—Fig. 20 is an illustration of one class of bench work; *a* represents the bushing of a piston valve in which two series of ports *b* and *c* must be cut out of the solid metal by hand. This same operation may be performed more economically on a milling machine, but it is frequently done by hand. The ports are laid out in the usual way, the outline *d* being clearly marked on the



FIG. 20.

painted surface. The bushing is then taken to the drilling machine and the ports are drilled out, just enough stock being left outside of the drill holes to insure a good finish. The holes may be drilled so close together that when the drilling is finished the block of metal may easily be removed by a blow with the hammer. The ridges between the drill holes are chipped away, as shown in the illustration, and the sides of the ports are finally finished to the lines by filing.

31. Key Seats.—Key seats in pulleys and gears are often chipped in. They are first laid out on both ends of the hub and lines drawn through the bore. If the key seat is a narrow one, a chisel of corresponding width is used, and the cut driven from each end; but if the seat is a wide one, two or more narrow parallel grooves are chipped through, and the stock between is removed with a flat chisel.

32. Cutting a Keyway.—The manner of laying out and cutting a key seat in a shaft is as follows: The key seat

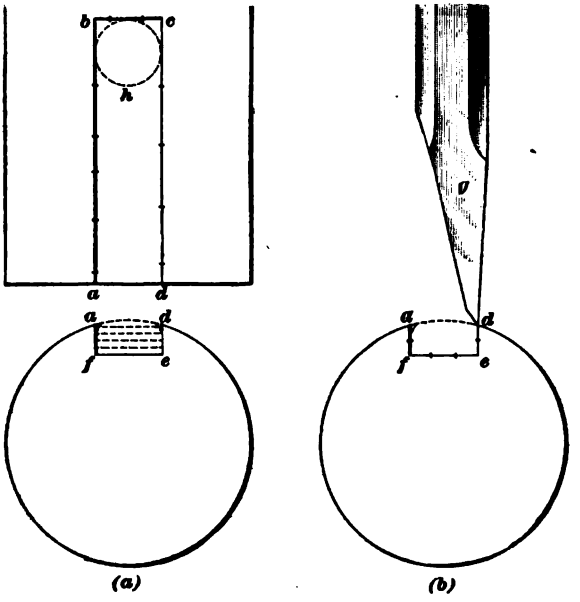


FIG. 21.

is first laid out as shown by the lines *a b*, *c d*, *e f*, Fig. 21 (*a*). The lines are sometimes marked with a prick punch, as shown. The side lines *a b* and *c d* of the key seat should be marked with a deep chisel cut, as shown at *a* and *d* in the end view, to prevent the material from tearing out along the sides of the keyway during the first cut with the chisel. This cut is best if made with a side chisel ground and held in the manner

shown at *g*, Fig. 21 (*b*). An ordinary flat chisel may be used for this mark, if ground quite thin and held at such an angle as to bring one of its cutting sides square with the side line *d*.

A cape chisel of proper width is used to remove the stock, several light cuts being driven through the key seat, as indicated by the dotted lines in Fig. 21 (*a*). The key seat, if long or at the end of the shaft, may be finished by filing, but when it is in the middle of the shaft this is impossible, and the finishing must be done with chisels.

It is sometimes considered easier to drill out the stock before chipping. This is done by laying out and drilling a line of holes like that marked *h*, Fig. 21 (*a*), down to the right depth and squaring the bottoms with a square-end drill and chipping the remaining stock to the lines. This is especially applicable to large key seats.

33. Chipping Large Flat Surfaces.—Large surfaces, whether flat or curved, are finished by chipping in the

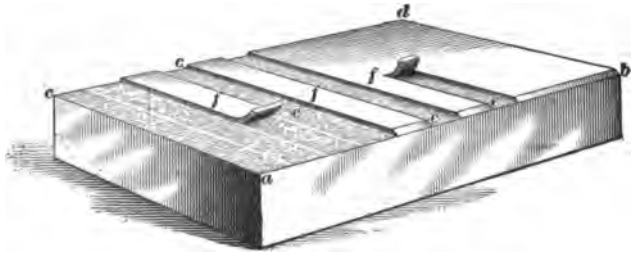


FIG. 22.

following manner: The piece is laid out as shown in Fig. 22, the lines *a b*, *a c*, etc. extending around the work in such a manner as to outline the edges of the required surface. In order to facilitate the starting of the chisel and to prevent the breaking off of the stock as the chisel leaves the work, it is well to chamfer the front and back edges, as shown at *a b* and *c d*. The stock above the lines *a b*, *c d*, etc. is removed by first cutting grooves *e*, *e* across the surface, leaving the ridges *f*, *f* between. These ridges are subsequently removed

with a flat chisel. In the illustration, the left-hand ridge has all been removed and half of the one next to it. By cutting the grooves across with the cape chisel, the work of the flat chisel is much reduced, as it has only straight cutting with no tearing or lifting of the metal at the corners. The width of the ridges *f* is determined by the width of the flat chisel to be employed, and should be as wide as the character of the material being cut will permit.

34. Chipping Strip.—The castings for boiler fronts and many other kinds of work are frequently fitted by chipping and filing. Work of this class has what is called a **chipping strip** on the casting wherever fitting is to be done. This strip is $\frac{1}{8}$ inch or more higher than the body of the casting, and wide enough to make the joint or fit. Castings to be fitted by this process are put together and their high spots noted, chalked, and chipped off. As the work progresses and the heavier parts are removed, red marking is rubbed on the work, and the parts are tried or rubbed together. The coating of red will be rubbed off on the spots that come in contact with the other part, thus showing more plainly where the chipping must be done. When the parts have been chipped to fit approximately, they are finally finished by filing.

35. Pneumatic Hammer.—The pneumatic hammer illustrated in Fig. 23 is sometimes used for chipping, and has

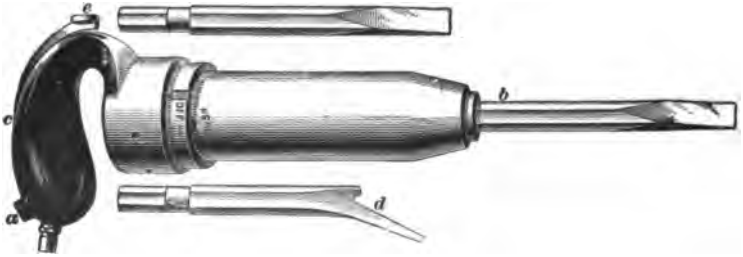


FIG. 23.

some advantages over the hand method. It is supplied with air at a pressure of about 80 pounds per square inch, through

a small hose connected to the hammer at *a*. The operator holds the chisel *b*, which has a hexagonal shank fitting a similarly shaped socket in the machine, in his left hand, as in ordinary chipping, and the machine is held by the handle *c* in his right hand, with the thumb on the trigger *e*. The whole is held firmly in position against the work, and light pressure applied to the trigger to start the chisel into the metal. As soon as the cut is started, more air may be admitted to the tool, making it strike harder and faster. The blows struck by this hammer are so rapid that the chisel has almost a continuous cutting motion. Heavy or light blows may be struck, as the operator desires, by regulating the pressure of the thumb upon the trigger.

Pneumatic machines of this type are used for many purposes, and have round instead of hexagonal bushings for holding the chisel. The chisel with the hexagonal shank is easily guided by the handle *c* of the machine, but the round-shanked chisel must be guided by the left hand. The tool shown at *d* is used for beading boiler flues and similar work.

36. Die Sinking.—Die sinkers do a great deal of chipping in finishing their dies. All the stock that can be is removed by some form of machining, and the inaccessible parts are chipped with special chisels and finished by filing and scraping.

37. Making Bottle Molds.—The lettering on glass bottles is made by letters cut into the bottle mold. The letters are marked off in the mold and then the operator chips them out, using a hammer weighing about 4 ounces. The main parts of the letters are formed by a V or diamond-shaped chisel, like the one shown in Fig. 18 (*h*) and (*i*). During this portion of the work the chisel is driven ahead, as in ordinary chipping; but to form the ends of the molds, the chisel is held in an upright position and driven downwards. A graving tool is used to smooth the letters, and bent or half-round files are used for smoothing the surface of the mold.

FILES AND FILING.

INTRODUCTION.

38. Use of Files.—In finishing machine parts, there are many cases where a smaller reduction in size or a more perfect surface is required than can be obtained by the use of machine tools or by chipping. Files are used for either of these purposes, for by their careful and skilful use great accuracy can be obtained. In order to make a rough surface smooth, files of various degrees of fineness are used, a coarse one first, followed successively by finer grades, the piece being finished with the finest.

39. Elementary Principle.—A file is made of a piece of steel of the desired shape and size, and has a series of grooves cut across its face. When a file is passed over the surface of a body of metal or other material, the teeth formed by the grooves act on it as a series of small chisels, each removing a small chip. By passing the file across the surface successively, the high parts are removed. Each file, however, leaves its own marks, and these are removed, if desired, by means of the finer grades.

DEVELOPMENT OF FILES.

40. Hand-Cut Files.—Formerly, all files were cut by hand with flat chisels, the spacing being gauged by the eye, shape of chisel, and weight of hammer blow. The steel from which they were made was forged to the required shape, with a tang on which to fasten a handle. The piece was then carefully annealed, after which it was ground and cut. The hardening was usually done by covering the file with a coating of some substance that protected the teeth from the action of the heat, but permitted the body to be heated to a temperature that would give the proper hardness when the file was plunged into a bath of oil or water.

41. Machine-Cut Files.—On account of the expense of hand cutting, various methods of cutting with machines

have been tried, with varying degrees of success. The first machine-cut files were cut with regularly spaced teeth. There are serious objections to this style of files, since, in filing, the teeth follow each other at regular intervals and drop into the cuts made by the preceding ones, causing chattering. The hand-cut files are more satisfactory, as the slight irregularity in the spacing is sufficient to prevent the chattering. This difficulty in machine-cut files was overcome by a few makers by two methods. It was found that by increasing the spaces between the teeth gradually from the end to the middle, and again decreasing as the other end is approached, enough variation may be produced to prevent the chattering, without causing enough change from the true spacing to affect the working conditions. By this method of cutting, called the *increment cut*, the two ends of the file are of the same coarseness, while the middle is somewhat coarser.

Files are also cut with the gradations of spacing running from one end to the other, the spacing being finer at the point and increasing gradually to the shoulder, thus accomplishing practically the same result as in the style mentioned above. This is also known as an increment cut.

Chattering is also prevented by cutting the teeth slightly out of parallel. By changing the direction of the deflection several times in the length of the file, enough variation may be obtained to avoid this trouble. Files cut in this way are largely used at the present time.

It has been found that by varying the angle of the motion of the file gradually during the forward stroke, when there is a tendency to chatter, the regularly spaced file will work smoothly and well, and hence this style of file is still used in many shops.

DEFINITION OF TERMS.

42. The following definitions are taken almost in their entirety from "Filosophy," one of the publications of the Nicholson File Company.

Back.—A term commonly used to describe the convex side of half-rounds, cabinets, pitsaws, and other files of similar cross-sectional shape.

Bellied.—A term sometimes used to describe a file having a fulness in the center.

Blunt.—A term applied in describing files that preserve their sectional shape throughout, from *point* to *tang*, as shown in Fig. 24 (*a*).

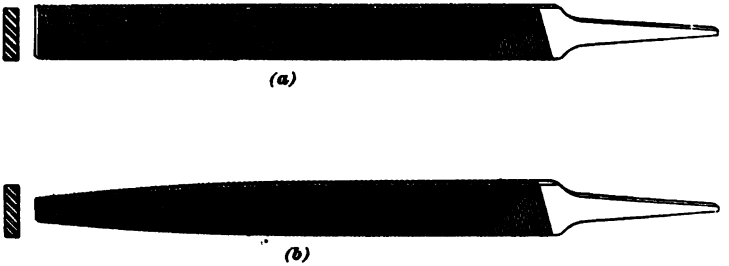


FIG. 24.

Equaling.—A term applied to describe a *blunt file* upon which is produced an *exceedingly* slight belly, or curvature, extending from *point* to *tang*, the file apparently remaining blunt.

Filing Block.—A piece of hard close-grained wood, having grooves of varying sizes on one or more of its sides. It is usually attached to the work bench by a small chain, and when grasped in the jaws of a vise is particularly useful in holding small rods, wires, or pins that are to be filed; also in filing small flat pieces that are held on the block by pins or by letting in.

Float.—The coarser grades of single-cut files are not infrequently called *floats* when cut for the plumber's use or for use on soft metals or wood.

Hopped.—A term known among file makers, and used to represent a very coarse, or *open*, spacing of the teeth (sometimes exceeding $\frac{1}{2}$ inch), mostly applied to the backs of half-rounds and to the edges of quadrangular sections.

Middle Cut.—A term used to designate the cut of a file when it is of a grade of coarseness between the *rough* and the *bastard.* It is but little used in this country.

Recut, or Recutting.—The working over of old or worn-out files by the several processes of annealing, grinding out the old teeth, recutting, hardening, etc., and thus again preparing them for use. This operation is sometimes repeated two and even three times; but the economy of recutting at all is very much questioned, and the practice is done away with in most of the best shops of the present day.

Safe Edge (or Side).—Terms used to denote that a file has one or more of its edges or sides smooth or uncut, that it may be presented to the work without injury to that portion which does not require to be filed.

Scraping.—As applied in machine shops, the process consists of removing an exceedingly small portion of the wearing surfaces of machinery by means of scrapers, in order to bring these surfaces to a precision and nicety of finish (as determined by the straightedge or surface plate) not attainable by the file or by any other means with which we are acquainted.

Superfine (or Super) Cut.—A term applied by the Lancashire file makers to designate a grade of cut known in America as "dead smooth."

Taper.—This term is used to denote the shape of the file shown in Fig. 24 (*b*), as distinct from blunt. Custom has also established it as a short name for the three-square, or triangular, hand-saw file.

DISTINGUISHING FEATURES.

43. Character of Cut.—The teeth of files are not generally cut at right angles to the sides of the file, but are set at an angle, as shown in Fig. 25. This angle varies for different materials. Files used in machine shops are cut in two different ways, known as *single-cut* and *double-cut.*

44. Single-Cut.—Single-cut files are cut with a single series of teeth running continuously from one end of the file to the other, as illustrated in Fig. 25 (*a*). They

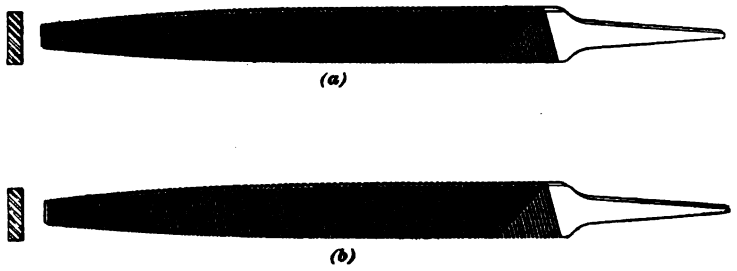


FIG. 25.

are used almost entirely for filing in lathes, and for the softer materials, such as lead, wood, horn, etc. The coarser grades are often called *floats*.

45. Double-Cut.—Single-cut files are rarely used in the machine shop, except on lathe work or on brass. By making another cut, at an angle to the first, or *over-cut*, a file is produced as shown in Fig. 25 (*b*), and is called a *double-cut*. The second, or *up-cut*, is generally cut a little finer and not as deeply as the over-cut. The angles that the two cuts make with the axis of the file vary for different uses, the over-cut ranging from 35° to 55°, and the up-cut from 75° to 85°. The up-cut has the effect of dividing the small cutting edges produced by the over-cut into a large number of small pointed teeth. Files thus made in various grades of coarseness give excellent results on the ordinary materials used in machine construction.

46. Coarseness of Cut. — American practice has divided machine-shop files into the following classes, with regard to their coarseness:

Single-Cut. — Rough, coarse, bastard, second cut, and smooth.

Double-Cut.—Coarse, bastard, second cut, smooth, and dead smooth.

The coarse and bastard cuts are used almost entirely on the coarser grades of work, and the second cut and smooth

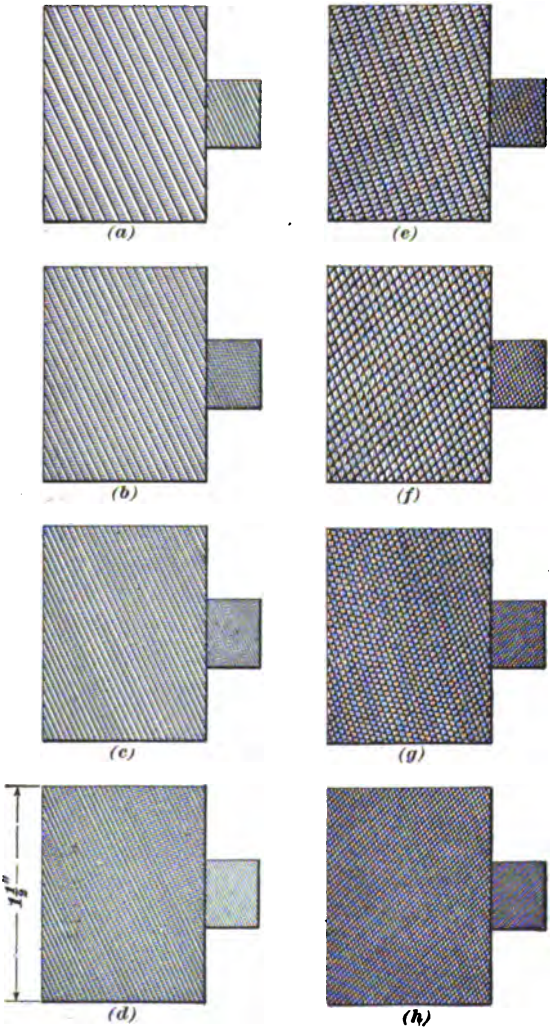


FIG. 26.

are used in finishing and for the finer classes of work. The rough and dead smooth are rarely used in the machine shop,

although occasionally a rough single-cut may be required where much work in lead or other soft material is necessary. The dead-smooth double-cut is occasionally used on extremely fine work, but it is required so rarely that many good mechanics never have occasion to use one.

The coarseness of the cut for each grade varies with the size of file, the cut being coarser on the larger files. Fig. 26 shows the comparative coarseness of 4-inch and 16-inch files, (*a*), (*b*), (*c*), and (*d*) showing the single-cut, rough, coarse, bastard, and second cut, and (*e*), (*f*), (*g*), and (*h*) the double-cut, coarse, bastard, second cut, and smooth.

STYLES OF FILES.

47. Files are divided into three general classes with regard to their cross-sections, viz.: *quadrangular*, *circular*, and *triangular*. Besides these, there are some other miscellaneous cross-sections, but they are not used in machine shops, and will therefore not be considered here.

The accompanying table, which is taken almost entirely from "Filosophy," shows the machine-shop files classed under these various headings, with their description and machine-shop uses, the first column showing the cross-section of each style. Many of these are used for other purposes than those mentioned, only their application to machine-shop work being mentioned here.

SIZES OF FILES.

48. The size of a file is generally indicated by giving the length in inches of the cut part, the tang not being included. Thus, a 10-inch bastard flat file means a bastard flat file 10 inches long from the point of the file to the tang.

BRITISH CLASSIFICATION OF FILES.

49. The classification of files in Great Britain differs slightly from the American classification; while the files of the two principal British makes, the Sheffield and the Lancashire, are slightly different. The naming of the Sheffield

CHARACTERISTICS AND USES OF FILES.

Comparative Cross-Sections of Files.	Name of File.	Common Lengths.	Character of Cut.	Coarseness of Cut.	Shape.	Use.
	Mill file. — Mill blunt file. — Round-edge mill file.	4 in. to 16 in.	Single-cut.	Mostly bastard.	Taper. — Blunt. — One or two round edges.	Sharpening mill saws, mowing-machine knives, etc. In machine shop, for lathe work, draw-filing, and to some extent for finishing brass and bronze.
	Equaling file.	6 in. to 12 in.	Double-cut.	Mostly bastard.	Blunt.	For general machine-shop work. (Seldom called for.)
	Flat file. — Flat blunt file.	4 in. to 16 in.	Double-cut.	Mostly bastard, many second cut and smooth, some dead smooth.	Taper. — Blunt.	Used by mechanics generally for a great variety of purposes—one of most common files in use.
	Hand file.	4 in. to 16 in.	Double-cut.	Mostly bastard, many second cut and smooth, some dead smooth.	Parallel sides and tapered thickness.	Preferred by machinists for finishing flat surfaces. Its shape and its having one safe edge make it particularly useful where the flat file cannot be used.
	Pillar file.	6 in. to 14 in.	Double-cut.	Mostly bastard, many second cut and smooth, some dead smooth	Parallel sides and tapered thickness.	For general machine-shop use on narrow work.
	Square file.	4 in. to 16 in.	Double-cut.	Bastard.	Taper.	Almost all branches of mechanical work; principally for enlarging holes of rectangular shape.
	Square blunt file.	10 in. to 20 in.	Double-cut.	Bastard.	Blunt.	For the rougher work in finishing or enlarging mortises and keyways, when of considerable length.
	Round file. — "Rat tail," or "mouse tail." — Round blunt file	4 in. to 16 in.	Single-cut (spiral).	Mostly bastard.	Taper. — Blunt.	For enlarging round holes and for shaping the fillets on internal angles.
	Half-round file. — Half-round blunt file	4 in. to 16 in.	Double-cut, single-cut on convex sides on grades finer than a bastard.	Mostly bastard, though many second cut and smooth and some dead smooth.	Taper — Blunt.	Wide use in machine shops.
	Half-round wood file.	8 in to 14 in.	Double-cut.	Coarse.	Taper.	Woodwork generally, occasionally on the coarser kinds of brass work.
	Three-square, or triangular, file.	6 in. to 14 in.	Double-cut.	Mostly bastard.	Taper.	For filing acute internal angles, clearing out square corners, filing up taps, cutters, etc.
	Cant file.	6 in. to 10 in.	Single-cut.	Mostly bastard.	Blunt.	Principally in shaping the inner angles of spanners or wrenches for hexagon bolt heads and nuts. It is but little known in America. It must not be confused with the cant saw file.

files with regard to their coarseness is as follows: rough, middle, bastard, second cut, smooth, and dead smooth. The finest grade of the Lancashire files is called "superfine," instead of "dead smooth." It will be seen that the "middle" corresponds to the American "coarse."

The degrees of coarseness represented by these various names in the Sheffield, Lancashire, and American classifications differ somewhat, but not enough to cause any material difference in the working conditions. A remarkable degree of fineness of cut has been attained, Lancashire superfine hand-cut files of the smallest size having been made with 300 cuts to the inch.

FILING OPERATIONS

50. Purpose of Filing. — In machine construction there are many instances where parts must be finished by hand. The part may have been finished as far as possible in a machine tool, but the surface could not be made sufficiently smooth, and must be finished by hand; or it may be so located, or of such a character, that a machine tool cannot be used, and the entire work must be done by hand. In the latter case, the excess of metal may be removed with a cold chisel, and the work then finished by filing.

It has already been said that a file consists of a series of minute chisels that are passed over the work by hand, under a pressure that is just great enough to make them cut. For rough work, the coarser grades of files are used; and as the surface becomes smoother, finer grades are used successively.

51. Difficulties to Contend With.—The operation of filing is one of the most difficult of machine-shop operations, and the quality of the work produced depends almost entirely on the skill of the workman. In most machine-shop operations, the tool is guided positively by some provision in the machine with which the operation is performed, as in a planer, shaper, or milling machine. In filing, the accuracy of the work depends entirely on the motion of the hands, without any means of guiding the tool positively.

It will be seen, therefore, that skilfulness on the part of the workman is essential to good work, the quality of the file being of secondary importance. A poor workman may be provided with a good file, but his work will not be good, while a good workman may do very good work with a poor tool. In order to do the best work, however, it is necessary to have a good file that is adapted to the work to be done.

52. Advantage of Convex Faces in Files.—To the unskilled it would seem at first thought that a file having a perfectly straight surface, bearing on the work equally at all points, is essential in order to do good work. A little experience will show that this is not true, and that a surface that is slightly convex will produce better results. In filing, the pressure of the hands is put on the two ends of the file, with the result that the spring thus caused tends to make the lower face concave; also, when files are being hardened, they have a tendency to spring, thus making it impossible to produce files that have perfectly straight surfaces.

In filing wide surfaces, a perfectly straight file would require a very heavy pressure to make it *bite* (take a cut); while the same file on a narrow surface would bite under a very light pressure. In the latter case, the pressure is concentrated on a few teeth; while in the former it is distributed over a large number, and in order to secure enough pressure on each tooth to make it cut, a very heavy pressure is necessary. It is found in practice that a light pressure with a small number of teeth in contact will produce the best results. By making the files convex, only a few teeth will be in contact at one time, however wide the surface may be. The faces of files are, therefore, made convex for three reasons: to overcome the effect of spring due to the pressure of the hands, to overcome the spring caused by hardening, and to make the file bite on any width of surface.

53. Wooden File Handles.—File handles are generally made by turning a piece of wood to the desired shape,

putting a ferrule on the end, and drilling a hole into it to receive the tang of the file. As the sizes of the tang vary for the different forms and sizes of files, the hole must be small enough to receive the smallest file for which it is intended. If the handle is made of a soft wood, the larger tangs may be driven in without splitting it; but when made of hard wood, it is necessary to enlarge the hole to about the right size. This may be done by heating the tang of a worn-out file of the same size as the one being filed, and burning out the hole in the handle. If no old file is available, the tang of the new file may be heated, but care must be taken that the temper of the file is not drawn. This may be prevented by wrapping a piece of wet waste about the file up to the tang. The handle should be driven well up to the heel of the file.

54. Special File Handles.—In filing broad surfaces, as the tops of lathe beds, and in finishing long slots, the ordinary wooden handle cannot be used and other devices have been brought into use. Fig. 27 shows a simple handle

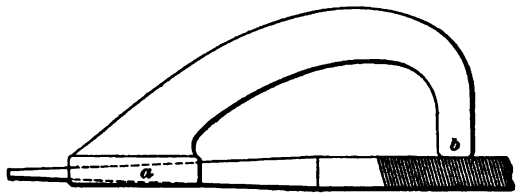


FIG. 27.

that has been found very efficient. The end *a* is formed with a dovetailed slot that slips over the tang, while the point *b* rests upon the back of the file. The slot should be made to fit about the middle of the tang of a 12-inch file. The foot *a* should be about 1½ inches long and the handle about ⅝ inch in diameter.

Another device that is frequently used and that has some advantage over the one just described is shown in Fig. 28. A foot *a* rests upon the file and has a dovetailed slot that catches over the tang. A rod *b* has a lug *c* on its front end

that catches over the point of the file. The handle *d* contains a nut that screws on the end of the rod *b*, and by

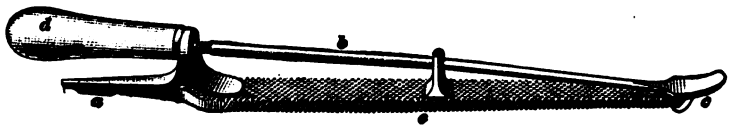


FIG. 28.

means of which the file is held firmly between the catch *c* and the foot *a*. A column *e* at about the middle of the file makes the device more rigid, and prevents the file from springing up in the middle when pressure is put upon it. A projection on the front end of the rod furnishes a convenient thumb rest. This device is used quite largely and has given excellent satisfaction.

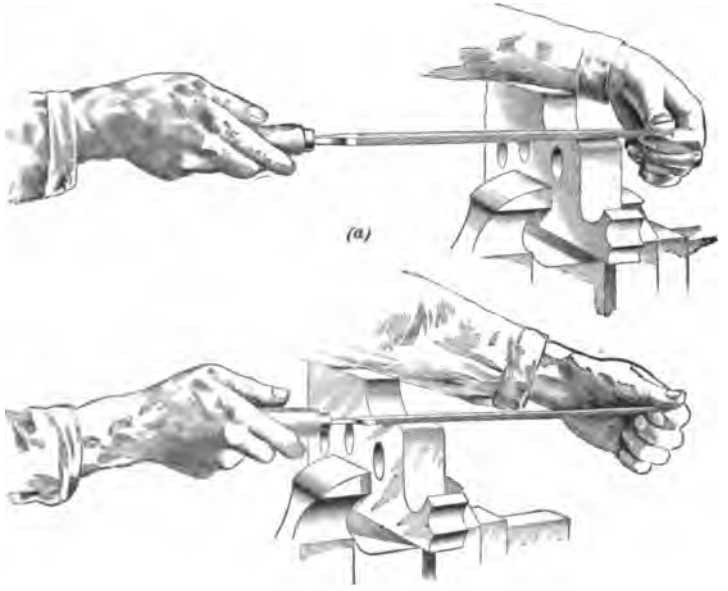


FIG. 29.

55. Holding the File. — It is very important for a beginner to acquire the correct manner of holding the file.

A right way is learned as easily as a wrong one, but having once become accustomed to the wrong, it is very hard to change to the right. There is some difference of opinion as to the correct way, but the following is considered good practice.

In moving the file endwise across the work, commonly called *cross-filing*, it is generally held as shown in Fig. 29 (*a*) and (*b*); for the lighter grades of work, and in finishing cuts, the former illustration shows the relation of the hands to the file at the beginning of the stroke, and the latter at the end of the stroke. The point of the file is held between the thumb and the first finger, as shown in the two views, while the handle is held by resting the thumb upon it, as shown in these

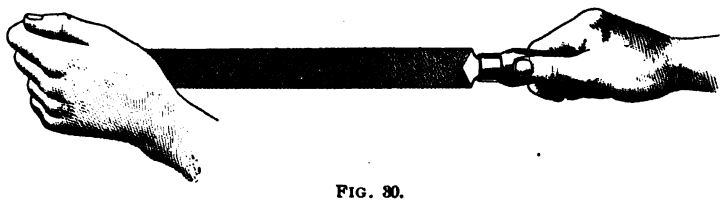


FIG. 30.

illustrations and in Fig. 30, and letting the end stand against the palm of the hand, the fingers gripping it lightly. When the work is heavy and a large file is used, the ball of the left hand is placed on the point of the file, while the handle may be gripped as shown in Fig. 30. It will be observed that in the latter case the handle is gripped a little farther forwards than in the case of light work.

56. When the file is very thin, there is great danger of springing it so as to round the corners. This may be prevented by holding it as shown in Fig. 31. A downward pressure is put upon both thumbs and an upward pressure upon the fingers of both hands. This pressure is just sufficient to overcome the tendency of the ends to spring downwards. By making the pressure great enough to spring the file downwards considerably in the center, a slightly concave surface may be formed.

It is very difficult, however, to hold a file in this way for more than a few minutes, and it is better to use a heavier

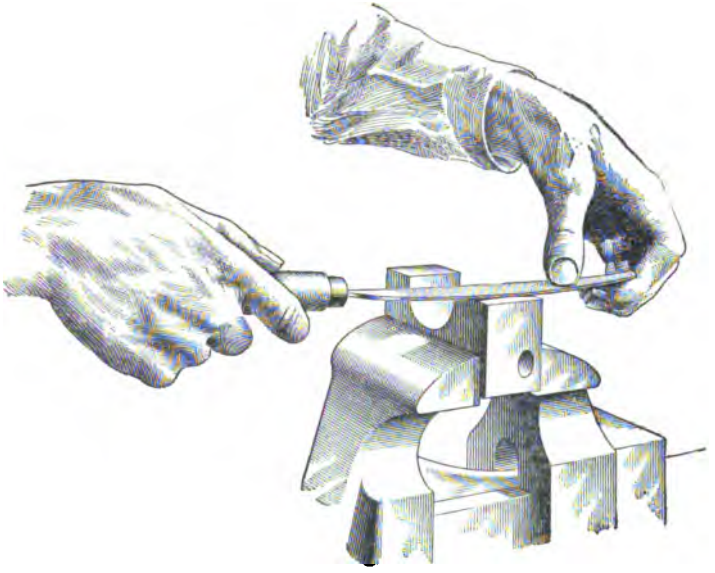


FIG. 31.

file that has considerable convexity and stiffness, whenever that is possible. On very light files spherical handles are often used.

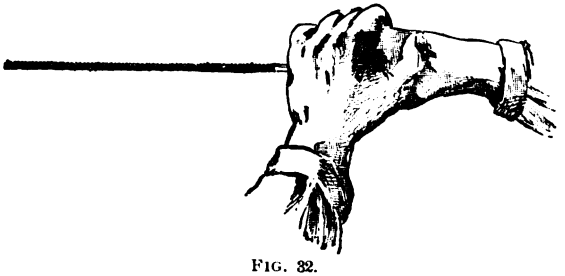


FIG. 32.

57. For internal work, when the hole is long, it may not be possible to hold the file at the point. In this case a very great stress comes on the wrist of the right hand, which

soon becomes tired. This stress may be relieved by placing the left hand over the right, as shown in Fig. 32. When the work is thin, so that the file will reach through the work far enough to take hold of the point, the ordinary method of holding it for outside work is generally used. In draw-filing, the file is grasped at each side of the work, as shown in Fig. 33.



FIG. 33.

58. Using the File.—Cross-filing, though the most common, is one of the most difficult forms of filing. In moving the file back and forth, there is a tendency for the hands to swing in arcs of circles about the joints of the arms, while the body sways more or less, depending on the work. To overcome these tendencies so as to move the file in straight lines requires a great deal of practice and careful observation of the results of certain movements. Filing on narrow work is especially difficult. The work becomes a fulcrum on which the file rests at different points along its course, and if an equal pressure is put on each end, it will tilt first one way, then another, depending on the point of contact and the leverage.

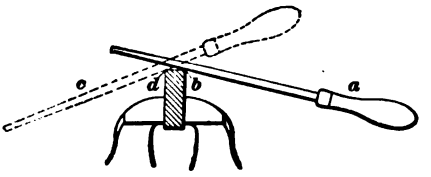


FIG. 34.

For instance, in Fig. 34, when the file is in position *a*, there is a tendency for the handle to tilt downwards from the fulcrum *b*; when in the position *c*, represented by the dotted lines, the point tilts downwards about the fulcrum *d*. As the file runs forwards, there is, therefore, a tendency to file off the corners more than the middle of the piece and to produce a convex surface. On wide work there is less

tendency to do this, and the beginner should, therefore, take his first lessons on work ranging between about 1 inch and 4 inches in width. By persistent care to have the file rest evenly upon the work, he may entirely overcome this difficulty, and not until he has accomplished this should he attempt to file narrow work.

59. Filing Broad Surfaces.—In filing broad surfaces, the danger of rounding the corners is reduced to a minimum, but other difficulties present themselves. Files for this class of work have convex faces, and only a few teeth cut at a time. The strokes must then be so gauged that an equal cut is carried across the entire piece. It is evident that if numerous short strokes are made they are liable to overlap each other at some places and not meet at others, and to wear out the files at the middle while the ends are still good. Uniform strokes of as great a length as possible should be made.

When high spots are to be removed, the file must be so held that the teeth over these spots are in contact with the work. By commencing the stroke with the teeth near the point in contact, and lowering the handle gradually to compensate for the convexity, the effective work of the whole stroke may be concentrated upon a small area. On the other hand, care must be taken so that this is not done when it is desired to remove the metal evenly from a broad surface, or a concave or irregular surface will be the result. In this case the file should move perfectly parallel to the work, or be gradually tilted so as to increase the length of the cut. Great care should be taken in all filing operations, and by constant practice the correct way of doing the work will be acquired and become second nature; whereas a continuous disregard of the correct methods will cause the incorrect manner to become habitual.

60. Diagonal Filing.—It will be noticed in filing that small grooves are left upon the work at each stroke, and when the strokes are all made in the same direction these grooves

become deeper; this increases the work that is to be done, for these marks must be removed by means of finer grades of files. By changing the angle of the direction of the stroke with the work, at short intervals, this difficulty may be avoided. This, too, will make the file cut more freely, since the grooves running at an angle to the cut cause the file to bite more freely and the particles to be separated more easily. It will also enable the workman to see where the file is cutting and to gauge the stroke so that the desired part of the surface will be removed.

Changing the course of the file as described above is often called **diagonal filing.** The angle that the strokes should make with each other depends on the work. Practice alone will enable one to determine what it should be.

61. Pressure on File.—In all kinds of filing there should be just enough pressure put upon the file during the forward stroke to make it cut freely; but there should be no pressure put upon it during the return stroke. The teeth of a file are formed approximately as shown enlarged in Fig. 35. It will be seen that when pressure is put upon the file, and it is moved in the direction of the arrow *a*, the cutting edges are well supported, and the angle of the cutting face and the clearance produce very good cutting conditions. When moving in the direction of the arrow *b*, which corresponds to the return stroke, the conditions are reversed. The angles are such that the teeth will simply drag over the work, without cutting, while the edges are not well supported, and any pressure put upon the file will cause the teeth to wear away very rapidly without producing any effect upon the work. In fact, the cutting edges of some of the teeth of a new file may be broken the first minute the file is used, and these teeth never do any work again.

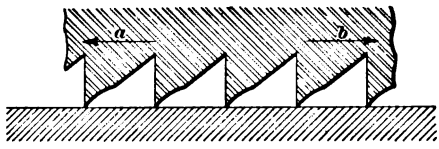


FIG. 35.

62. Filing Curves.—In filing circular holes, a round file that is as nearly the size of the hole as it is possible to obtain should be used. A small file will tend to produce the ridges shown in Fig. 36; with a larger file that conforms more nearly to the curvature of the hole, this tendency is greatly reduced. When the filing is to be done on an internally curved surface of a large radius, as shown in Fig. 37, a half-round file is used. As in the case of the circular hole, there is a tendency to file unevenly, and a file of as large a curvature as is obtainable should be used.

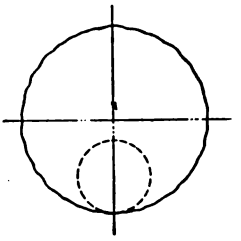


FIG. 36.

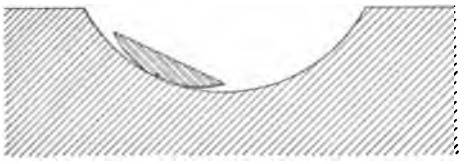


FIG. 37.

The file should be moved along the circumference of the curve as well as across the work, which gives it a diagonal motion, and in addition to the advantages of diagonal filing on flat surfaces, prevents the formation of ridges.

63. Filing Into Corners.—When it is necessary to form a sharp corner, or to file up to a finished surface that stands at right angles to the one on which the filing is done, a safe-edge file is used, thereby preventing any injury to the finished part. When the corner is to be extremely sharp, a half-round file may be used, or a flat file may be ground off on one side, to form a safe edge. Either the half-round or a flat file ground in this way has a sharp edge that will permit a sharp angle to be formed. Some forms of triangular files will also make a sharp corner. The other files used in ordinary work are so cut that the corners are either rough or slightly rounded and will not make a clean, sharp angle. When the corners are to be rounded, a round-edge file will give good results.

64. Filing Slots With Curved Ends.—For filing out slots that have been roughed out by drilling, and where the end of the slot is to be rounded, a flat, round-edged file is the most suitable. When the sides have been machined to size and the end of the slot is to be rounded, a round file with the sides ground off to the width of the slot, as shown in Fig. 38, may be used. Two safe edges *a* and *b* are thus formed that will prevent injury to the finished sides.

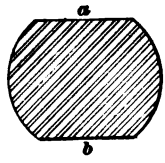


FIG. 38.

65. Draw-Filing.—When the filing is done by moving the file sidewise across the work, it is called **draw-filing.** Fig. 33 illustrates how the file is held, the motion being at right angles to its length. Draw-filing is used very generally in finishing turned work, where it is desired to remove the circular tool marks and lay the marks endwise. Care should be taken to hold the file so that the teeth will cut as it moves away from the body, and to relieve the pressure on the return stroke, as in cross-filing.

In draw-filing, the cut is not so deep as in cross-filing, the teeth standing at such an angle to the direction of motion that a light shearing rather than a cutting effect is produced; very smooth work may be done by this method. A second-cut or smooth file is best suited for draw-filing. On convex surfaces a flat file or the flat side of a half-round file may be used; but in concave work a round file or half-round file will give the best results. When a large amount of metal is to be removed, it should be done by cross-filing, as the cut in draw-filing is so light that a very great amount of time would be required to remove it by this method.

66. Finishing Filed Work.—When a better finish is required than can be produced by draw-filing, the surface may be rubbed with fine or worn emery cloth and oil, the cloth being wrapped about a file or a piece of wood, which is used as in draw-filing. The strokes should be made successively along the circumference of a cylindrical piece, in order that the finish may be even. When a very fine finish

is required, the draw-filing may be followed by cross-filing with a dead-smooth file, after which it may be rubbed with the emery cloth in the direction in which the draw-filing was done.

67. Position of Body When Filing.—No attempt should be made to keep the body rigidly in one position while filing, especially on heavy work. A free, easy motion of the body, in the direction in which the file is moving, permits a greater force to be exerted without undue strain. In filing right-handed, the workman stands with his left foot toward the work, and as the file is moved forwards, a slight bending of the left knee will tend to throw the body against and upon the file, thus assisting in making the cut. During the return stroke the knee is again straightened as the body returns. A little practice will show the extent to which this motion of the body can be made to assist in the work.

68. Height of Work.—The height of the work largely depends on the class of filing that is to be done. Ordinarily, the surface to be filed should be about as high as the elbow of the workman. When the work is extremely heavy it should be set somewhat lower, in order that a greater pressure may be put upon it. If the vise or supporting device is too high, a foot-board or low bench may be used to stand upon. The feet of the bench should be set flush with the ends of the board, in order to prevent tipping when stepping upon the ends.

69. Effect of Oil.—The effect of oil on filing varies greatly with different metals and different classes of work. In finishing broad, smooth surfaces of cast iron, the presence of oil prevents the file from cutting, and causes it to slip over the surface, thus wearing off the sharp points of the teeth.

On cast iron, generally, and especially on the class of work mentioned above, oil should never be used. On the other hand, it may be advantageously used when filing wrought iron and steel, and other hard fibrous materials, especially in finishing surfaces, when the file is new and sharp. Oil prevents the file from scratching and cutting too deeply.

Sometimes the teeth are filled with chalk, either dry or mixed with oil; this, to a great extent, prevents the filings from clogging between the teeth. New files are usually sent from the factory covered with oil, to prevent their rusting. For work in which oil is objectionable this must be removed, which is sometimes done by first rubbing off the surplus oil, then coating the file with chalk and brushing it off carefully.

70. Selection and Care of Files.—The life of a file may be prolonged very materially by exercising care in selecting a suitable one for each piece of work, and in using it properly. A new file should never be used on rough cast iron from which the sand and scale have not been removed, nor on narrow surfaces. Both these conditions tend to break and dull the teeth. A well-worn file will do excellent service in both these cases. On narrow work, a worn file will give better results than a new one, the teeth on a new file being so sharp that the few teeth in contact will enter so deeply that they are liable to be injured and to scratch the work. A new file should be first used on brass or wide surfaces on smooth cast iron.

The files most commonly used in the machine shop are the 12-inch and 14-inch flat and half-round bastard, the double-cut, and the 12-inch and 14-inch single-cut. The other files mentioned are, of course, needed very frequently for finishing, or for special operations, and should be kept in stock.

One of the most serious troubles to contend with in filing is the tendency to *pin*. The cuttings clog between the teeth, forming hard, sharp "pins" that scratch the material.



FIG. 39.

This is known as *pinning*, and occurs more readily in some materials than in others. As soon as the slightest indication of pinning is observed, great care should be taken to prevent it. The teeth should be carefully cleaned. Sometimes this

may be done by rapping the file against a wooden block or the work bench, or by rubbing the hand over it. In most cases it is necessary to use a wire brush, called a *file card*, shown in Fig. 39. Vigorous brushing in the direction of the teeth usually removes the pins, but in cases where the brush will not remove them, a piece of soft sheet brass, or copper or iron wire flattened out at one end, may be used. The end is pressed crosswise upon the teeth and moved in the direction of the length of the teeth. Little grooves will be cut into the soft metal, forming small teeth that clean the file thoroughly.

71. Files should never be thrown upon one another, or upon other tools or hard substances. In too many cases, files, hammers, cold chisels, wrenches, and tools of all kinds are thrown into a box or cupboard promiscuously, resulting in injury to the files and all other cutting edges, to say nothing of the careless and dilapidated appearance of the place and the time wasted in trying to find anything that is wanted. A tool box or cupboard should always be kept in order. There should be "a place for everything and everything in its place" when not in use. Files should be laid either upon shelves or in a drawer that is provided with small divisions so as not to permit them to rub against each other. They should always be carefully cleaned before they are put away, and kept in good condition so as to be ready for use when they are required.

72. Filing Jigs. — These are generally used in the making of duplicate parts, and in a great variety of operations where it is necessary to produce accurate work by filing, and to do this practically independent of the skill of the workman. Such jigs usually consist of hardened steel blocks fastened to the work, and made in suitable shapes to guide the file so as to remove the stock to the proper form in each case. The file will glide over the hardened jig practically uninjured and cut away the softer metal of the piece of work which projects above it.

One form of jig is shown in Fig. 40. This jig is used in making rectangular slots in boring bars, etc. It consists of a hardened steel block *a*, having a hole for inserting the

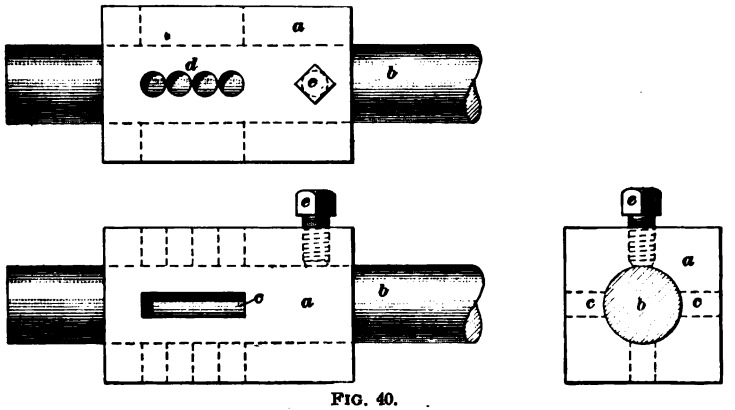


FIG. 40.

work *b*; a rectangular slot *c* of the dimensions required to be made in the work; a series of holes *d* at right angles to the slot *c* and circumscribed by a rectangle same as *c*; and a setscrew *e* to hold the jig on the work.

In cutting such a slot in a bar, the jig is slipped on to the proper position and clamped by means of the setscrew. The holes are then drilled through the work, those in the jig serving to guide the drill. The setscrew is then loosened and the jig turned 90°, bringing the rectangle over the holes just drilled. A plugger may be used to drive out some of the metal between the holes, after which a file is used to bring the slot to the form of that in the jig.

A better way is to move the jig a half hole endwise, then run an end mill through each hole of the jig to remove the metal left between the holes by the drill; the slot may ther be finished by filing as described above.

FITTING KEYS.

73. Rectangular Keys.—Keys of a square or rectangular cross-section are generally planed or milled a little larger than the size of the key seats they are to fill, and are

then filed to fit. If the key is to fit top and bottom, it should be filed true to a surface plate and made of such width as to fill sidewise the key seats in both shaft and wheel. The corners should be slightly rounded, as well as the ends. The shaft is now put into the bore, with the key seats in line. Red or black marking should be put on the surfaces of the key seat, and the key driven in lightly and taken out and filed where it shows bearing marks. Care should be taken not to drive the key too tightly at first, as it is easily sprung to conform to the inequalities of the hole, and will show a greater bearing than it should. Care must be taken not to drive the key in dry, as it will surely cut. The marking applied to the seat is sufficient at first, and later the marking material may be put on the key, where it serves the double purpose of marker and lubricant. By repeated trials, the key is brought to fit the seat perfectly, and then may be driven home without danger of throwing the work out of true.

A well-fitted hub and shaft may be forced considerably out of true by driving a key that is tight only on one end; and poorly fitted wheels and shafts may be made to run reasonably true by using care in fitting the keys and trying the work on lathe centers as it progresses. If means are not at hand for machining keys, as is often the case on repair work, a wooden pattern is first made and the key forged a little large, after which the scale may be ground off on an emery wheel or grindstone and the key filed to fit.

74. Provision for Withdrawing Keys.—Keys that can be driven out by putting a set in the opposite end of the key seat are not provided with heads; but if the seat is so located that only one end is accessible, that end must be provided with a head, as shown at *a*, Fig. 41, for the purpose of withdrawing the keys. A pinch bar, or wedge, is used between the head *a* and the hub, to back this key out.



FIG. 41.

For convenience in fitting, large keys are sometimes made with an extension head 3 or 4 feet long, as shown in Fig. 42.

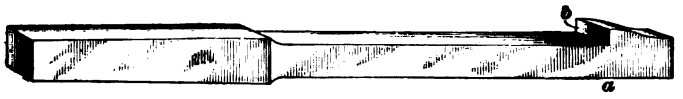


FIG. 42.

While backing out such a key, it should be supported by holding a sledge under the head at the point *a*, while blows are being struck against the face *b*.

75. Taper of Keys.—When keys are made with a taper, the taper is generally furnished by the drawing room, but in some shops the workman is left to determine this for himself; in common practice, $\frac{1}{16}$ inch to $\frac{1}{8}$ inch per foot is found sufficient.

76. Round Keys.—Sometimes a cylindrical or tapered pin is used as a key. In this case a hole is drilled one-half in the shaft and one-half in the hub; and if the key is to be tapered, the hole is reamed to the proper taper. A key is then turned up to fit the hole, and fitted by filing in the lathe, after which it is driven home. For very small work where there is not much strain on the parts, this style of key may do very well. It is used very generally to fasten the hand wheels of globe valves to the stems. For large work, and especially where there is not a good fit between the hub and the shaft, such a key should never be used, as it has a tendency to burst the hub.

77. Woodruff Keys.—These keys are made by cutting a disk from a piece of cold-rolled stock, and then splitting it into two pieces along its diameter. The keys thus formed are of the form shown in Fig. 43. The key seat in the shaft is made by sinking a milling cutter, of a diameter corresponding to the curve on the key,

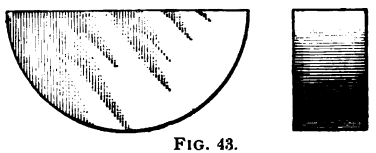


FIG. 43.

into the shaft to such a depth that the proper amount of the key will be left out of the shaft. The key is driven into the shaft, and the wheel, which has previously been key-seated with a seat whose depth is one-half its width, is driven lightly on the shaft, and, if the work has been correctly done, the key has only to be slightly filed to let the wheel into its place. This key bears sidewise, and should just fill the top and bottom. It is a short key, and when a greater length is required two or more are put in line.

BENCH, VISE, AND FLOOR WORK.

(PART 2.)

BENCH WORK AND LAYING OUT.

TOOLS AND FIXTURES EMPLOYED.

SCRAPERS.

1. Use of Scrapers.—Scrapers are used in machine construction to fit or correct flat bearing surfaces to each other and to make flat or curved surfaces true. These surfaces when flat are first planed, or in some cases milled, as true as possible; but owing to the unequal hardness or texture of the material, the possible springing of the work when clamped on the planer or milling-machine table, and the slight wear of the finishing tool, they are never perfect as they leave the machine. Errors in planed surfaces such as the fitter is called on to correct by scraping are caused in several ways, the most common of which are wind, caused by not having the casting or piece firmly bedded on the table; out of square, caused by using try-squares that are not true; angles that do not match, caused by carelessness in setting the head to the angle; and by sand holes, spots of scale, and hard spots, that the tool always jumps or slides over. The errors in planed work should not exceed one or two thicknesses of tissue paper, and if found to be greater,

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the work should be sent back to the planer, unless it is found that the errors are due to hard spots.

2. Forms of Scrapers.—The scrapers used on flat and angular work are the flat, the hook, the right-hand hook, and the left-hand hook; and for curved work, the half-round and half-round end are much used. For removing burrs and scraping corners and countersunk surfaces, the three-cornered scraper is generally used. The flat scraper is the one most used, as it is the easiest to make, sharpen, and use, and in expert hands it will remove an astonishing amount of surface in a short time with little effort.

Scrapers are often made of old files, but they do not work well, because files are made of a grade of steel, called *file steel*, that can be properly hardened only by the special processes used by the file manufacturers. The half-round and three-cornered scrapers may be made from any good smooth or dead-smooth files that have become too dull to use, by simply grinding off the teeth, thus avoiding the necessity of rehardening.

3. Three-Cornered Scraper.—The three-cornered scraper may be made of a worn-out file of any good make. The file should have all the teeth ground off and the end sharpened at an angle of about 60 degrees. It is best to do



FIG. 1.

the work on a wet grindstone, for if done on an emery wheel and overheated, the scraper will be spoiled. The appearance of the finished three-cornered scraper is shown in Fig. 1. In some cases the edges from *a* to *b* are slightly curved.

4. Flat Scraper.—The flat scraper, Fig. 2 (*a*) and (*b*), should be made of any one of the best grades of tool steel, such as Jessop's, or of the special scraper steel furnished by

several American makers. It should be made of stock about $\frac{3}{16}$ inch thick by 1 inch wide, with a tang, similar to that on a file, which is driven into a wooden handle. The cutting edge should be drawn to about $\frac{1}{16}$ inch thick by $1\frac{1}{4}$ to $1\frac{5}{8}$ inches wide, and hardened to the greatest possible degree.

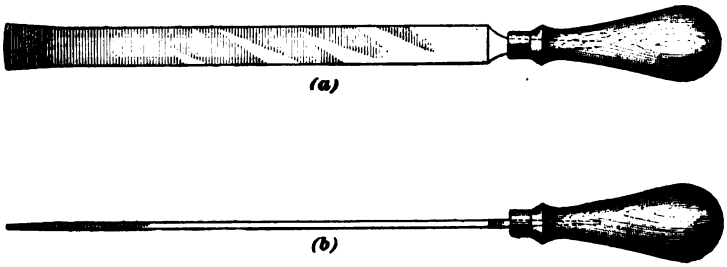


FIG 2.

The sides should be ground flat, and the end may be slightly rounded. The end should be ground by moving it back and forth along the tool rest, parallel to the face of the grindstone, thus making two equal cutting edges, as is shown exaggerated in Fig. 3, which shows the end of the scraper as it leaves the grindstone. The surfaces *a* and *b* are next rubbed on a good oilstone, after which the tool is held in a vertical position so that both of the points *c* and *d* will rest on the stone, in which position it is rubbed back and forth, grinding it into the shape shown by the dotted line *e f*. This makes the thin end of the scraper practically flat. It is now ready for use and has an equally good cutting edge on each side.

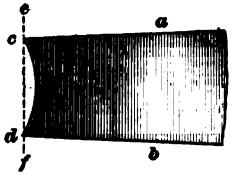


FIG. 3.

5. Bent, or Hook, Scraper.—The bent, or hook, scraper is made in the form shown in Fig. 4 (*a*). It should be made with the same care as the flat scraper, and should be ground to the angles denoted by the lines *a f* and *c d*, Fig. 4 (*b*). The cutting end is made of the form shown at Fig. 4 (*c*). The cutting is done with the edge *e*. The face *b h* is ground to any convenient angle so as to reduce

the area of the surface *b e*, which must be finished on an oilstone. For fitting angular surfaces that cannot be

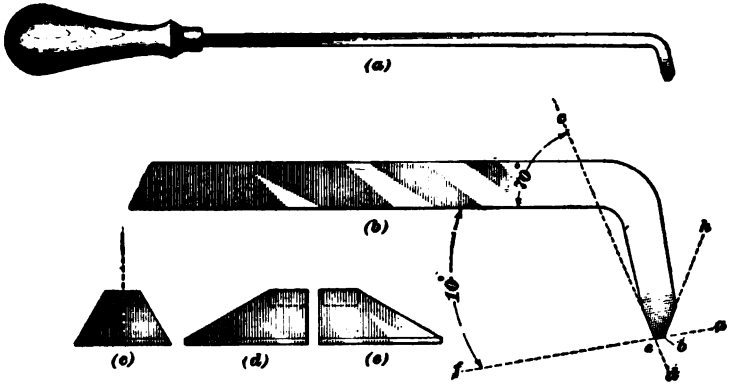


FIG. 4.

reached conveniently by the straight and regular hook scrapers, the right-hand and left-hand hook scrapers are made, as shown in Fig. 4 (*d*) and (*e*).

6. Holding the Scraper.—The manner of holding the flat scraper is shown in Fig. 5. The handle is held in

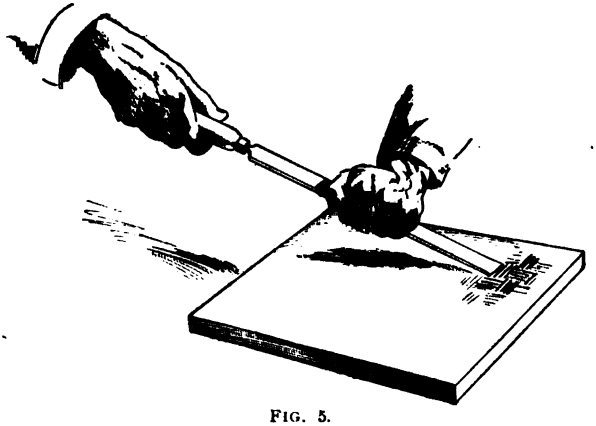


FIG. 5.

the right hand, with the thumb extended along the top, in order to keep the muscles of the hand and arm in line, the

same as in filing, thus preventing cramping the hand and tiring the arm. The left hand is applied as near the cutting edge as is convenient, and only enough pressure applied as is necessary to remove the required amount of metal. The cutting is done by pushing the scraper away from the operator, except where it is used for frosting, flowering, or finishing, when a long handle may be substituted and rested on the shoulder, while both hands are used to pull the tool toward the operator. The hook scrapers are held in much the same way as the flat scrapers, but are pulled toward the workman.

7. Proper Angle for Holding the Scraper.—The flat scraper is usually held at an angle of about 30 degrees to the surface of the work, but this angle may vary with the material scraped and the condition of the cutting edges. No definite angle can be given for other types of scrapers; it must be determined by trial with each scraper and each class of work.

SCRAPING A PLANE SURFACE.

8. Preparation of Surface.— A newly planed surface is scraped in the following manner: The piece is placed on any support that will bring it up to a convenient height for the workman, who first brushes off any dust or dirt that may be on the surface. He next runs a smooth or dead-smooth file over the surface, to remove any burrs or fuzz that may be on it, and he also touches off any marks that would indicate that a sand hole or hard spot had left a high spot or spots.

9. Applying the Surface Plate.—A surface plate, prepared by thoroughly cleaning and then coating with *marking material*, is now placed face down on the work and rubbed back and forth a few times over the entire surface. No pressure is necessary, the weight of the plate being sufficient. When the plate is removed, irregular patches of the marking material will be found on the work. These places indicate high spots in the surface, and they are

removed with a few strokes of the scraper. The workman now wipes his hand clean of grit and rubs it over the entire face of the surface plate, to smooth the marking, and then rubs the plate over the work again. More bearing spots will be shown this time, which are removed with the scraper. The work proceeds in this manner until the entire surface of the work is covered with bearing marks, when it may be called true.

The marking material, in addition to showing the high spots on the work, acts as a lubricant and prevents undue wear on the plate and the cutting or scoring of both work and plate. The more true the surface operated on becomes, the thinner should be the coating of marking on the plate. For some purposes the marking does not afford sufficient lubrication, and additional oil would prove detrimental to the work. This difficulty may be prevented by using a plentiful supply of turpentine on the surfaces while they are being rubbed together. In addition to lubricating the surfaces, it also facilitates the work of scraping.

10. Marking Mixtures.—These may consist of red lead or Venetian red in lard or machine oil or any similar materials, red or black, that are not gritty. In some cases, special mixtures are furnished by the shop management and their use insisted on. The marking is rubbed with the hand into a thin coating as evenly as possible over the plate, which is now ready for use. It is well to keep the marking mixture in a tin box provided with a cover, so that it can be kept clean and free from grit. Venetian red is better than red lead, on account of the fact that it is much finer in texture.

DRILLS AND DRILLING.

11. Drilling Ratchets. — Ratchet drilling is the slowest method of drilling holes, and should not be resorted to if the work can be done by any of the machine processes, such as the drill press, portable drills, and pneumatic drilling machine; but there are places where none of these can

be used or are available and in which cases the ratchet must be used.

Ratchets are generally made single acting; that is, the drill only cuts during the forward stroke of the handle; but some of the improved ratchets are made to give a forward rotary motion to the drill or cutter during both strokes. Ratchets are made to use both square- and taper-shank drills.

The taper-shank twist drill is the better tool, but it often happens that odd sizes are needed by men out on repair work, where it is impossible to get the proper size of twist drill, and a square-shank flat drill can be made by any blacksmith or by the man himself, or a flat drill already on hand may be made into the required size in a few minutes, either by grinding or dressing.

12. Use of Drilling Ratchet.—The ratchet is used for drilling in the following manner: The hole to be drilled

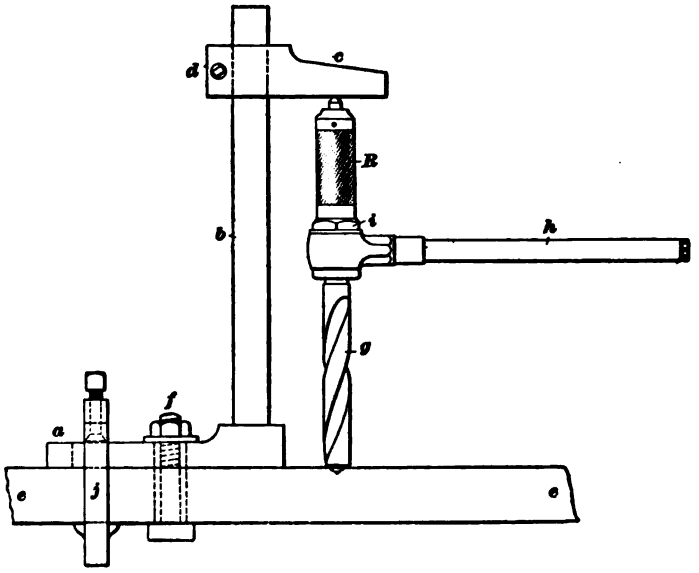


FIG. 6.

is laid out in the usual way and center punched. Means must be provided to force the drill into the material, which

is usually done by providing some sort of brace, or, as it is commonly called in the shop, an *old man*, or a *drilling crow*, that will serve to support the ratchet and drill in the correct position and at the same time allow the drill to be forced into the work by the feed-screw.

The brace, drilling crow, or old man, is made in a great variety of ways, from a piece of flat iron or steel bent to the proper form to the well-designed adjustable one shown in Fig. 6. This consists of a base *a* having an upright *b* carrying an adjustable arm *c* that is held by the binding screw *d*.

The base is made fast to the work *e* by means of a bolt *f* or clamp *j*, as shown. The arm *c*, which has a number of center holes in its lower face, is set to such a height that the ratchet *i* and drill *g* will go under it. The drill is set square with the work, or it may be set to lean slightly away from the upright, as the pressure upwards on the arm *c* will spring the upright *b* back and so draw the drill about perpendicular. The drill is rotated by means of the handle *h* and is fed into the work by means of the sleeve *R*.

13. Special Ratchets.—Ratchets for repair work and for use in contracted spaces are often made very short, and have square holes in their spindles, so as to use very short square-shank drills. They are also used in erecting machinery to ream holes in line.

14. Crank-Driven Portable Drill.—The crank-drill is a better tool than the ratchet, where there is room enough to use it. This form of drilling machine is clamped to the work and is operated by a crank that gives a continuous motion to the drill. The feed is operated either automatically or by one hand, and the crank is turned by the other. These drilling machines will work at any angle and form a very useful tool for heavy work.

15. Scotch Drill.—The Scotch drill is a drilling device formed very much like an ordinary carpenter's brace. It is usually made by bending a piece of steel or

iron so that it will form the necessary crank, providing one end of it with a suitable socket for the drill, which may be either square- or taper-shanked. The other end is provided with a pointed center that may be fed out by means of a screw, thus giving the feed to the drill. The crank is rotated like an ordinary carpenter's brace, the device being held in place by a knee or other suitable clamping device. Sometimes the Scotch drill is made with two cranks arranged like a ship auger, so that both hands may be used at the same time, but usually only one hand is employed, as the other is required to operate the feed-nut.

16. Breast Drill.—The breast drill is so named from the fact that it is provided with a suitable guard that may be placed against the breast while drilling, the feed being obtained by a pressure brought to bear on the drill by the body. The drill is usually operated through bevel gears by a crank on the side of the machine. This style of drill is very largely used for drilling small holes for attaching name plates, and for similar light work.

BROACHES AND BROACHING.

17. Broaching.—Broaching, or **drifting,** is the process of forming holes by forcing a cutter of the exact form required through holes previously drilled. In all broaching operations, the greatest amount of stock possible must be removed by drilling, and if much remains for the broaching tools, they should be so designed that each tool will be given an equal amount of material to take out.

18. Simple Square Broach.—The form of broach depends largely on the nature and quantity of the work to be done. If this is only a small amount, the broach must be as inexpensive as possible. In this case, most of the work is thrown on the drills or other means used for roughing out the hole, and the broach depended on only for finishing the hole.

The simplest form of broaching is illustrated in making a socket to fit a ½-inch square in a tap socket or a chuck-screw wrench. The square may be laid out on the end of a piece of round stock, as in Fig. 7. A ½-inch circle *a* is first drawn from the center mark *b*, and the square *c* is laid off. Four ⅛-inch holes *d* are now drilled ⅛ inch deeper than the hole is to be and just touching the lines of the square. The ½-inch hole is next drilled, which leaves the hole as shown in Fig. 8 (*a*). A square piece of steel having the proper temper may now be driven easily to the bottom of the hole. Fig. 8 (*b*) shows this form of broach; it tapers a little from the cutting edge *e* to *f*.

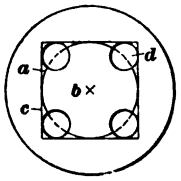
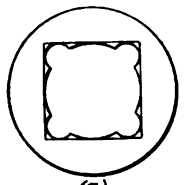
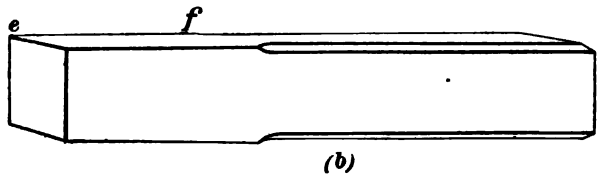


FIG. 7.


(a)



(b)

FIG. 8.

19. Use of Several Broaches in a Set.—In cases where there is a considerable amount of any given class of work to be done, it is best to use several broaches following one another, each removing a portion of the stock. In the case illustrated in Figs. 7 and 8, the greater part of the metal at the corners was removed by drilling small holes, and in some cases some additional metal was chipped out. If there is much of this work to be done, all the metal in the corners may be removed by passing a series of broaches through the work. In Fig. 9, the forms of four broaches for squaring a ½-inch round hole that extends through the piece are shown at *e*, *f*, *g*, and *h*. All the broaches should be provided with several cutting edges, as shown between *b* and *c*, and a

guide pin, as shown at *a b*, in the upper part of Fig. 9, which represents the finishing broach.

20. Making a Set of Broaches.—The pieces of steel to form the set are first centered and milled to the size of the square, after which the guide from *a* to *b* is turned to the size of the largest hole that can be drilled inside the square, which in this case is $\frac{1}{2}$ inch. The toothed part from

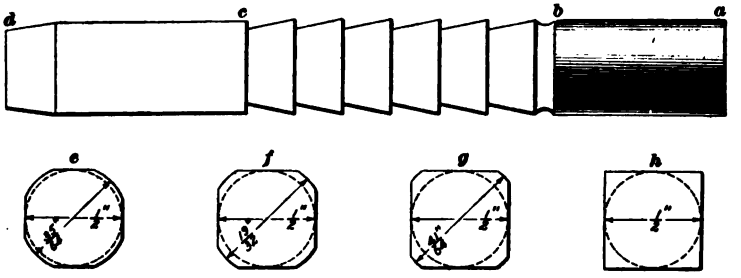


FIG. 9.

b to *c* is cut either by milling or planing, or the teeth may be cut in the lathe and afterwards backed off for clearance by hand. The size from *c* to *d* should be made slightly smaller than the toothed part, so that it will easily pass through the hole.

The various broaches of the set are made of such form that each takes out nearly an equal amount of stock. The broach marked *e* is driven through first, and is followed in succession by *f*, *g*, and *h*, which finishes the hole to size.

21. Grinding the Teeth. — In a new broach, the teeth from *b* to *c* are all of the same size, so that only the leading teeth cut and those behind simply steady the broach. As the front teeth become dull, they are ground on the front or flat face, and thus are reduced in size, so that the other teeth farther back must be depended on to do the finishing.

In preparing the blanks for the broaches shown, the corners in the broaches *e*, *f*, and *g* can be turned off in the lathe, and if desired both the cylindrical and the flat surfaces

can be finished by grinding after hardening. The broaches described are intended to be driven by a hammer, but they may be forced through by a power or hydraulic press.

22. Broaching Keyways. — Keyways may be broached more quickly and accurately than they can be chipped by hand. In some cases, quite large and long keyways are formed in this way, the broaches being driven by means of sledges.

The necessary tools for broaching keyways are shown in Fig. 10. First there must be a plug, Fig. 10 (*a*), turned to the proper diameter *c d* so that it just fits the bore of the hub, and it must be of sufficient length to pass entirely

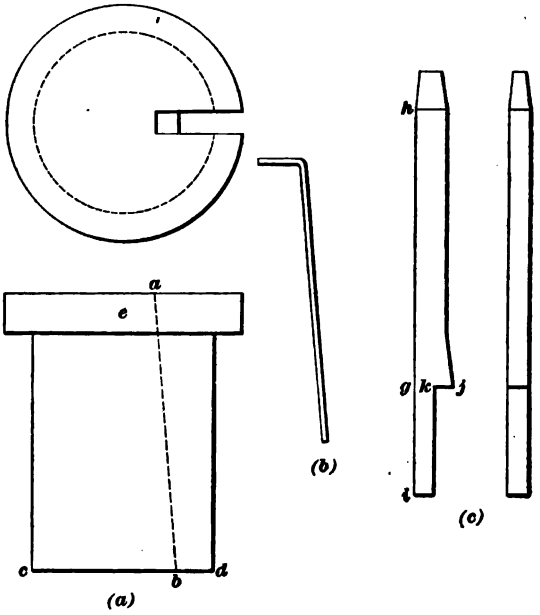


FIG. 10.

through the hub. The plug is provided with a collar *e*, which prevents it from passing too far into the hub. A slot or keyway having the same taper as the required keyway in the hub is cut in the plug, as indicated by the dotted line *a b*.

The cutting in the hub is done by the tool shown in Fig. 10 (*c*). The cutting edge is at *j*, and the thickness *g j* must be equal to the depth of the narrow end of the slot *b d*. In order to make the broach cut, liners are placed in the groove behind the broach; one of these liners is shown at Fig. 10 (*b*). The liners are made of sheet metal, and, if the keyway is a large one, after several thin liners are in place they may be removed and replaced by one thick one, after which the thin ones may be replaced one by one, as the successive cuts are taken. This method of employing some thick liners reduces the number of joints that can be compressed as the broach is being driven, and so makes the work more uniform.

The broach is provided with a guide *g i*, which enters the hole first, and the portion *g h* must be at least equal in length to the slot *a b*, so that the broach can be driven clear through. The face *j k* of the broach should be perpendicular to the face to be cut. The broach, if very large, may be made of machine steel and provided with an inserted blade or cutter at *j*. The cutting edge of a broach should be hardened to a brown or dark straw color.

23. Machine Broaching.—Broaches for large holes, or for large numbers of similar holes, such as are met with in manufacturing, are forced through the work by power-driven machines or hydraulic presses that support the work

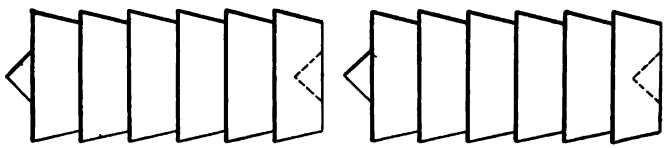


FIG. 11.

and also guide the tool. Broaches used in these machines are designed with special reference to the form of the hole and the quantity of stock to be removed, and a dozen broaches may be made to work out a single form of hole, each one taking a light cut.

Broaches for the machine work may be made, as shown in Fig. 11, with a countersunk center in the head and a corresponding external center on the point. The No. 1, or smaller, broach of a set is forced downwards as far as it will go, and then the No. 2 is placed on it, with its point in the reamed center to guide it; this one, also, is forced downwards, driving the first one through. This is repeated until all the broaches have been driven through the hole. In some cases, a single broach is forced through by hydraulic



FIG. 12.

pressure and made to finish a hole in one operation. Fig. 12 shows a broach and broached piece. The broach in this case has rounded corners, which illustrates a practice that should be followed wherever practicable, as teeth of this form are much less liable to break than those of square-cornered broaches. The notches *a* allow the broach to be started without taking the whole cut, and when it has entered far enough to have sufficient support to steady it, the whole teeth *b* commence cutting and finish the work.

24. Angle of Broach Teeth.—The teeth on broaches are sometimes cut diagonally across the sides, but these do not cut as easily as those cut square across, and they also have a tendency to force the broach to one side or to make it take a spiral course, thus causing some of the teeth to run into the stock and make a rough hole. For this reason, the teeth are generally made straight across.

25. Lubrication of Broaches.—For cutting most metals, broaches require an abundant supply of lard oil. In broaching keyways in cast iron, oil is not required so much for the cutting operation, but the back and sides of the broach should be well lubricated.

REAMERS AND REAMING.

26. Object of Hand Reaming.—The continued use of machine reamers dulls their cutting edges and at the same time slightly reduces their diameters. For some work, a hole $\frac{3}{1000}$ inch under size, such as would be produced by a worn reamer, would not be objectionable, but in addition to being small, the hole will be comparatively rough. These defects may be overcome by hand-reaming the hole.

27. Ordinary Hand Reamer.— The hand reamer shown in Fig. 13 illustrates one form of this class of tools. The body *a* is finished to the correct standard size, and the shank is made of such size that it will act as a guide when

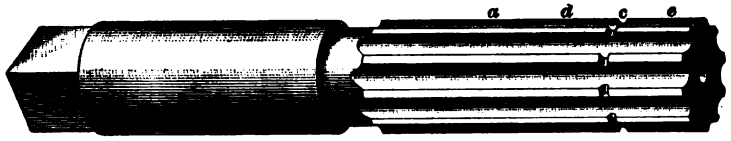


FIG. 13.

the hole to be reamed is longer than the fluted part *a*. A groove *c*, turned about one diameter from the lower end, serves as a stopping place for the wheel while grinding, and below this the diameter is about $\frac{3}{1000}$ inch smaller than at *a*. From the point *c* to *d*, about one diameter, the reamer is tapered up to the full size, and from *d* up it is parallel. The hand reamer is used, as its name implies, only by hand. The end *e* is entered into the hole left small by the undersized machine reamer and acts as a guide, and the taper from *c* to *d* removes the stock, while the parallel part *a* maintains the size. The small amount removed insures the durability of the tool and the smoothness of the hole. For cast iron and brass, the reamer should be entered and twisted through the hole, using enough pressure to force it through quickly. In the case of cast iron, the use of oil will give a smoother hole than can otherwise be obtained. For wrought iron and steel, it should be well lubricated with lard oil.

28. Step Reamer.—The reaming of taper holes, particularly large ones, in tough and hard metals, is greatly

facilitated by using the step reamer illustrated in Fig. 14. The small end *a* of this reamer is made the size of the small end of the hole. A hole of a size corresponding to *a* is drilled into or through the work as required. The step reamer is then started in and run to the necessary depth. This reamer cuts only on the end of each step, as at *b*, *c*, etc., the diameter of the reamer being slightly less at the top of each step than at the lower end; for instance, the diameter is smaller at *e* than it is at *d*, in order that the tool may not bind in the hole. Clearance is also given the cutting edge

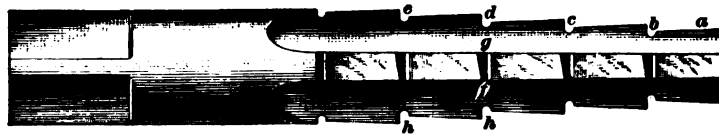


FIG. 14.

from *f* to *g*. This reamer is cut with four flutes, and therefore has four sets of cutting edges. The half-round notches *h* are cut to make a stopping place for the wheel while grinding. The use of this reamer does away with the necessity of using a number of different-sized drills to prepare the hole for reaming. After the step reamer has removed the stock, a notched taper reamer is run in to remove the steps, and after that the finishing reamer smooths the hole. Step and taper reamers intended for use in the lathe or by hand are provided with square shanks, but when made for use in drilling or boring machines they must be provided with taper shanks, so as to fit the sockets.

29. Taper Reaming.— Taper holes are frequently hand-reamed, to make them of the correct size and smoothness. This is done after the stock is removed by the roughing and finishing reamers. The taper hand reamer, when not in use, should be kept in a box or tied up in a heavy paper covering, as any nick or dent on its cutting edges will seriously mar the hole. The taper hand reamer must be used with great care. It should be carefully placed in the hole, well oiled if in wrought iron or steel, and turned with

enough pressure to insure its cutting from the very first; for turning a taper hand reamer in a hole when it does not cut will soon ruin it.

Valve bushings, which must be perfectly smooth and parallel internally, are often reamed with undersized machine reamers and then forced into place, after which a hand reamer is run through them to correct their defects.

30. Advantage of Vertical Reaming.—All reaming, whether hand or machine, is better if done in a vertical position. This is so because the weight of the reamer, if working horizontally, tends to ream downwards, and so

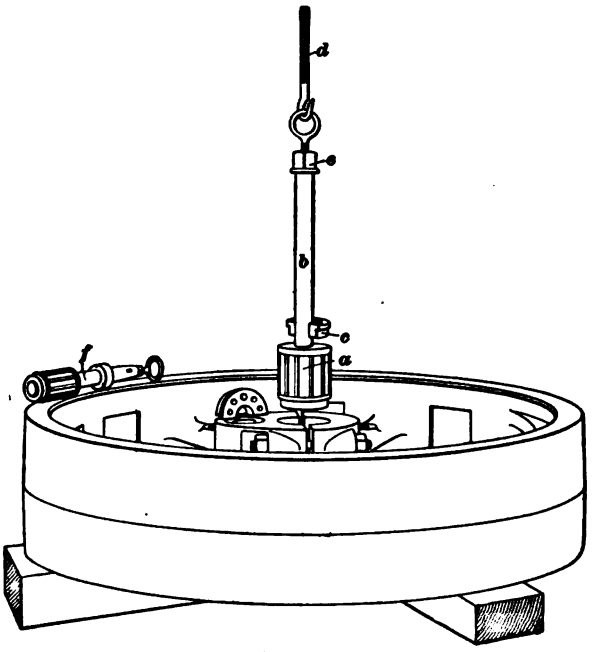


FIG. 15.

either carries the reamer out of line or tends to take more out of the bottom side of the hole. Also, any chips or cuttings will fall out of the vertical hole, but in the horizontal hole they remain between the teeth of the reamer and often scratch or score the work.

31. Example of Vertical Reaming.—Fig. 15 shows the practice of a prominent engine builder. The pulleys for these engines are first put on the boring mill and turned to $\frac{1}{16}$ inch over the finished size; the hole is bored about $\frac{1}{32}$ inch small and then hand-reamed to size, after which the wheel is put on a mandrel and the face turned true and to size. The reaming is done in the following manner: The wheel is placed on blocks, as shown, and the reamer's shank *b* is passed up through the bore and hooked to the threaded rod *d*. A split bush *c* is placed around the shank *b* and pushed down into the bore to act as a guide. A double-end wrench is placed on the square of the shank at *e*, and two men walk around the wheel to turn the reamer. The threaded rod *d* passes through a nut, not shown in the cut, and this feeds the reamer *a* upwards through the hole. The reamer *a* is shown just as it leaves the finished hole. Another finishing reamer is shown at *f*.

32. Reaming Holes in Line.—Holes may be reamed in line in the following manner: The holes in two or more castings that are to be bolted together are first laid out as close as possible to their correct location; all those in one piece are drilled and reamed to size, and the corresponding holes in the next piece are drilled about $\frac{1}{8}$ inch smaller; then the two castings are clamped together in their correct position, and a reamer the same size as the finished hole, which will cut only on its end, is put through the reamed part of the hole and ratcheted through the smaller hole, thus bringing them perfectly in line. This work must often be done in very contracted or limited spaces, and for such work, special reamers, called rose bits or rose reamers, must be made.

INSIDE THREAD CUTTING.

33. Methods of Tapping.—Holes are threaded in three ways: first, by cutting in the lathe; second, by using a special tapping fixture in the drilling machine; and third, by hand. The first two methods provide their own means

of keeping the tap square with the work, but in hand tapping much depends on the skill of the workman.

34. Squaring Tapped Holes.—Two sorts of hand taps are in common use. The first kind, Fig. 16 (*a*), is made

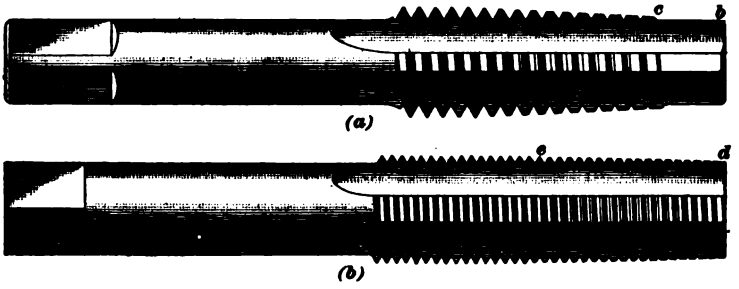


FIG. 16.

with a parallel end *b c* the size of the bottom of the thread. This parallel end fits the hole made by the tap drill, so that by the exercise of a little care on the part of the user a squarely tapped hole is the result.

The other style, Fig. 16 (*b*), is tapered from *d* to *e*; consequently, it will not stand square with the hole. To tap a hole square with (*b*), the tap should be well oiled, placed in the hole, and given two or three turns with a double-ended wrench. At this point remove the wrench and apply a square to the tap in the manner shown at *a*, Fig. 17. Try the square at the next flute, and if the tap shows out of square apply pressure enough sidewise on it with the wrench while turning to bring it square with the surface. Repeat these trials until the tap is found to be square. If a square is not at hand, a wide

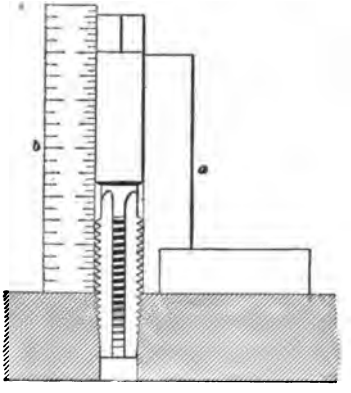


FIG. 17.

6-inch steel rule may be used instead, as at *b*, Fig. 17. The tap shown in Fig. 16 (*a*) will go in reasonably straight, but the beginner will do better work with it by using the same precautions as with the other style.

35. Tapping Jig.—The tapping jig shown in Fig. 18 is sometimes used. It consists of a piece of iron or steel bent to the form shown at *a*, Fig. 18 (*a*). The bottom surface *b c* is planed flat, and a hole *d* the size of the tap shank is drilled square to *b c*. A plug *e* is turned to fit *d* and the hole *f* to be tapped. To use this tool or jig, put

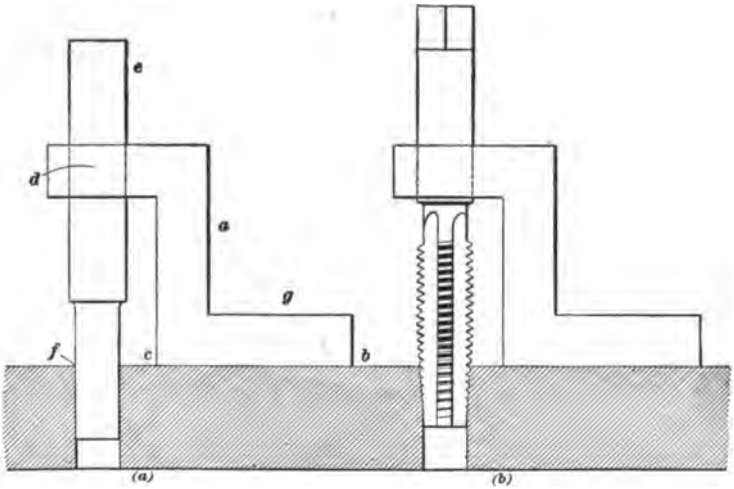


FIG. 18.

the plug into the hole *d* and then push it into *f*, as shown; clamp the jig *a* fast at the point *g*, and see that the plug *e* fits easily in both holes; remove the plug, and replace it with the tap, which will be held in the correct position to tap the hole, as shown in Fig. 18 (*b*). The hole *d* in the jig may be made as large as the largest tap, and a set of bushings made to adjust it to taps having smaller shanks.

36. Producing Smooth Threads.—It is sometimes desirable to tap holes with particularly smooth threads.

This may be done by first tapping the hole with a V-thread tap and then following it with a tap having the United States standard form of thread. The V-tap thread will leave enough material so that the United States standard thread tap will perform the same work in the tapped hole that the hand reamer does in the plain hole.

37. Number of Taps Necessary.—Ordinary holes in thin stock may be tapped in one operation by running the taper tap clear through the piece; but if the hole is of great depth, or of hard material, a second, or plug, tap must be run down, to relieve the long cut made by the taper tap. By using these two taps alternately, holes may be tapped to any depth that the taps will reach. Neither the taper nor the plug taps will thread a hole clear to the bottom, so when this is necessary, a third tap, called a *bottoming tap*, is screwed clear to the bottom of the hole. Care should be taken in using this tap, as the end teeth are easily broken by the heavy cut.

38. Pipe Threads.—The threads on pipe are of the V type, and to insure tight fits the threaded parts are made tapering. The standard taper for the threaded portion of pipe is $\frac{1}{16}$ inch to the inch or $\frac{3}{4}$ inch to the foot. The holes to be tapped for small sizes of pipe are usually drilled to the size of the bottom of the thread at the small end of the tap, and then the pipe tap run down to the proper depth; but for the large work, a reamer having the same taper as the tap is run in to take out some of the stock. This reaming leaves the right amount of stock for threading, and saves unnecessary wear on the tap.

WRENCHES.

39. Double-End Wrench.—The wrenches used for turning taps and hand reamers are made in a great variety of forms. Some are made solid, with one or more holes for

different-sized shanks, but the best wrenches are made of the form shown in Fig. 19. This wrench is adjustable to several different sizes of tap squares. The length of the handles of different wrenches of this type are proportionate to the diameters of the taps on which they may be safely



FIG. 19

used. Holes must frequently be tapped in spaces where wrenches of this type cannot be turned, and the single-end wrench must be substituted; but, where practicable, an extension should be placed on the tap and a double-end wrench used, as by this means holes can be tapped more nearly true and the danger of breaking the tap is reduced to a minimum.

40. Special Double Wrench. — Special forms of wrenches are sometimes made for special work. The wrench shown in Fig. 20, which is commonly used in the boiler shop, and sometimes in the machine shop, may be taken as an illustration of this class, and may suggest others that are

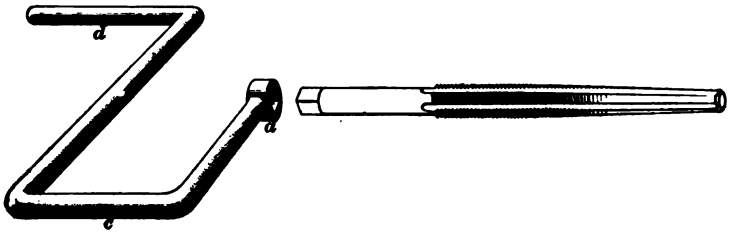


FIG. 20.

suitable for special operations. The tap wrench illustrated in Fig. 20 is called a *staybolt tap wrench*, and is made of $\frac{7}{8}$-inch round steel bent to the form shown. The square hole *a* is provided for the special staybolt tap shown. Two handles *c* and *d* are formed by the bends, and by using both

hands, the tap may be given a continuous rotary motion. Whenever possible, these taps are screwed clear through and taken out on the other side, instead of screwing them back again, as is done with the ordinary hand tap.

41. Single-End Wrenches. — Single-end wrenches are made both open and closed; that is, they are so arranged that they simply enclose three sides of a square nut, or four sides of a hexagonal nut, or are so made that they entirely surround the nut. The open-end wrenches have certain advantages, in that they do not have to be slipped over the end of the bolt or nut; they are made both with the sides of the jaws parallel to the line of the handle and with the sides of the jaws set at an angle to the center line of the handle.

For some purposes the straight wrench with the sides of the jaws parallel to the handle, as illustrated in Fig. 21, is suitable, but for work in contracted spaces it is best to give a wrench intended for hexagonal heads or nuts an offset, as shown in Fig. 22. This offset should be 15 degrees. The manner of using the wrench is illustrated in the four views in Fig. 22. In Fig. 22 (*a*), the first hold is shown, the wrench *a* being placed on the nut *f*. In this case, the wrench handle *b* operates betweeen the obstructions *c* and *d*. The wrench is first placed as shown in Fig. 22 (*a*), and the handle moved to the left into the position shown in Fig. 22 (*b*). The wrench is then turned over and placed on the nut, as shown in Fig. 22 (*c*), when it may be given another movement, bringing it into the position shown in Fig. 22 (*d*). This will have advanced the nut one-sixth of a revolution in two moves, from which it will be seen that 12 movements are necessary to make a complete revolution; as there are 360 degrees in the whole circle, it is evident that the nut is moved 30 degrees at each stroke of the wrench. If the wrench were made straight, as shown in Fig. 21, it could not

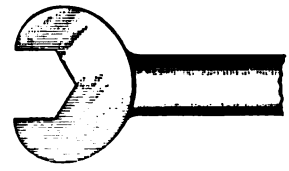


FIG. 21.

be operated in the manner illustrated in Fig. 22, but the nut would have to be so located that there would be a clear space in which the wrench could make one-sixth of a revolution.

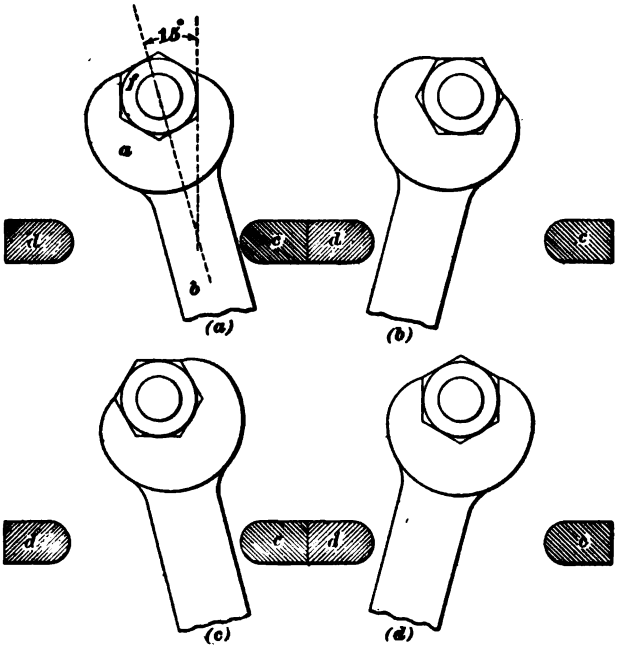


FIG. 22.

42. The open-end wrench is especially adapted for screwing on nuts, screwing in cap bolts, etc., but for operating taps, a **closed, or solid-end, wrench** similar to that shown in Fig. 23 is required. These may be made with the sides of the jaws parallel to the handle, as shown in Fig. 21, or they may be made with the sides offset, as shown in Fig. 22. If the wrench is intended for a square-end tap, the offset

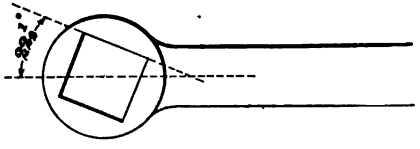


FIG. 23.

should be one-half of 45 degrees, or 22½ degrees, as shown in the illustration. This will enable the operator to advance the tap ⅛ of a revolution, in case there are obstructions so placed that it is impossible to make a greater fraction of a turn than this.

43. Socket Wrenches.—The most common form of socket wrench is illustrated in Fig. 24 (*a*). It is used to turn nuts and bolt heads set in recesses below the surface of the work, as illustrated in Fig. 24 (*b*). These wrenches are made with either square or hexagonal sockets, as the work may require. The sockets are made by laying out the desired form on the end, drilling one or more holes to remove the majority of the stock—in the case of a large wrench, chipping out some of the remainder of the stock, and then broaching the hole to the desired form. Socket wrenches may be made with the sides of the opening in the end of the wrench parallel or perpendicular to the handle *b*, Fig. 24 (*a*), which will give results similar to that shown in the open-end wrench in Fig. 21; or they may be made with a 15-degree offset for hexagonal wrenches, and 22½ degrees offset for square wrenches, as illustrated in Figs. 22 and 23. The offset is generally not as important in the socket wrench as in the solid-end or open-end wrench, on account of the fact that the shank *c*, Fig. 24 (*a*), of the wrench is usually made long enough to clear all obstructions.

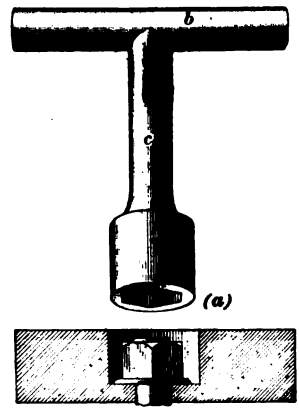


FIG. 24.

44. Socket Extensions for Wrenches.—When it becomes necessary to tap holes in contracted spaces, or to screw in studs or bolts in such locations, it is sometimes possible to reach the work by means of a socket extension

similar to that shown in Fig. 25. This consists simply of a long stem *a* having at one end a socket *c*, of the form required to fit the work, and a square *b* on the other end intended to fit any ordinary double-end or single-end wrench. Usually, these socket extensions are used only with double-end wrenches.



FIG. 25.

45. Ratchet Wrenches.—In the case of practically all single-end wrenches, it is necessary to remove the wrench and replace it on the nut after a portion of a revolution has been made. As there are a great many places where nothing but a single-end wrench can be used, much valuable time is lost in this changing of the wrench. To overcome this difficulty, ratchet wrenches have been introduced. A good type of adjustable ratchet wrench is illustrated in Fig. 26, in which the jaws *a* can be adjusted by means of the screws *b* so that they will accommodate a number of sizes. A handle *c* can be moved forwards through whatever portion of a stroke the location will permit, and then return for another stroke. It is possible

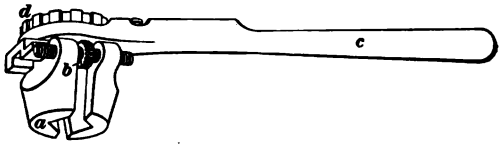


FIG. 26.

to make as small a fraction of a revolution as one tooth of the ratchet, shown at *d*. This style of ratchet wrench has but a single pawl engaging the ratchet, and hence there is bound to be some lost motion before the pawl takes hold of a tooth on the forward stroke.

46. Teeth of Ratchet Wrench.—It is advantageous to have the teeth of the ratchet as coarse as possible, so as to give them the requisite strength; in order to obtain the

effect of fine teeth, which give the least amount of lost motion, the multiple-pawl ratchet has been introduced. This is illustrated in Fig. 27, in which the ratchet *a* has 12 teeth; 5 pawls *b* are so placed that only one of them will

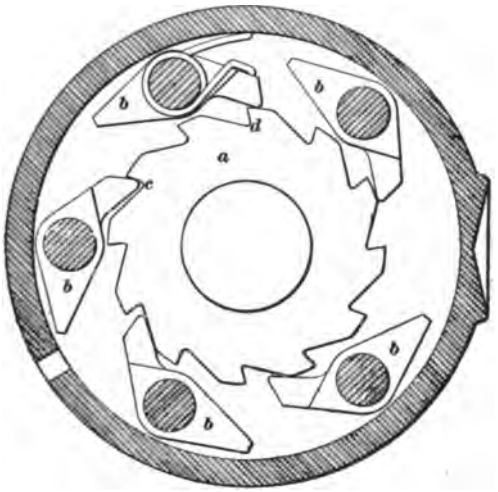


FIG. 27.

engage a tooth at a time, as shown at *c*. By moving the pawls back $\frac{1}{5}$ of a space between the teeth, the next pawl will come in contact as at *d*, and hence the lost motion cannot be greater than $\frac{1}{5}$ of $\frac{1}{12}$, or $\frac{1}{60}$, of a revolution.

47. Studbolt Wrench.—For driving studs by means of a ratchet, a special stud holder is provided, as shown in

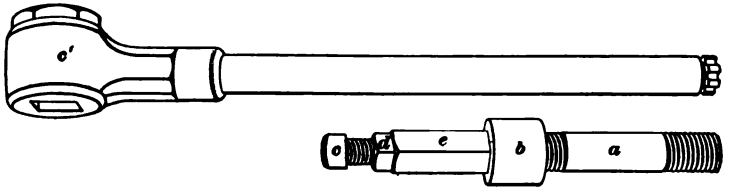


FIG. 28.

Fig. 28. The stud *a* is screwed into the socket *b*, and then the point of the setscrew *c* is run down against the end of

the stud so as to lock it in the socket. The setscrew *c* is held in place by means of a locknut *d*. A stud driver is operated by means of a ratchet on a square *e*. This style of stud driver is ordinarily used in a very thin ratchet, as shown at *c'*.

Ratchets may also be applied to socket extension wrenches where these must be used in locations in which a complete revolution cannot be made. The time saved in putting the studs into a single large engine will usually more than pay for the price of a ratchet wrench and suitable stud driver.

OUTSIDE THREAD CUTTING AND PIPEWORK.

48. Die Stock and Square Dies.—Outside threads of various pitches and sizes must often be cut by hand. Dies for such work are made to cut threads on pieces ranging from $\frac{1}{16}$ inch to 2 inches in diameter. A form of stock and die that has many advantages is shown in Fig. 29 (*a*). The stock *a* has an oblong opening *b* provided with guides

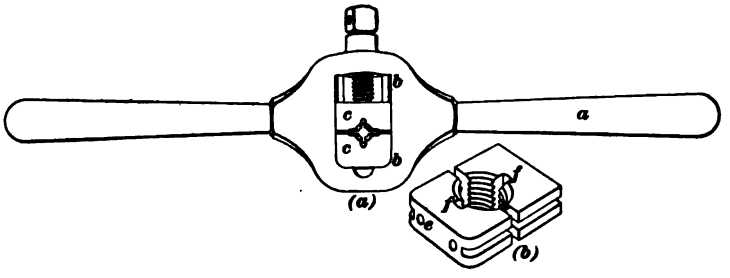


FIG. 29.

for holding the split die *c*, which is closed by a setscrew. The form of these dies is shown in Fig. 29 (*b*). They are so constructed that the cutting is done at the points *f*, which also steady the dies when starting on the work. Bolts can be threaded standard, undersize, or oversize with these dies. For example, a No. 14 screw, a $\frac{1}{4}$-inch, or a $\frac{9}{32}$-inch screw, all 20 threads per inch, can be fitted with one pair

of dies. They may be made in any size and should be tapped with an oversize tap in order to provide clearance. These dies are especially adapted to repair work where the variety of work is great and the quantity small. With these dies several cuts must be taken to cut a full thread. A pair of blank dies with suitable notches cut in them, used in this stock, makes an excellent tap wrench.

49. Die Stock and Round Dies.—Standard work is best done with any of the many forms of round dies, one of which is illustrated in Fig. 30 (*a*), (*b*), and (*c*). When in use,



(*a*) (*b*) (*c*)

FIG. 30.

the die is held in a die stock, of the form shown in Fig. 31. The die is made of two parts *a* and *b*, Fig. 30 (*a*) showing the two parts in place; Fig. 30 (*b*), the die with one part



FIG. 31.

removed, and the latter being shown detached in Fig. 30 (*c*). This die can be adjusted within narrow limits, the screw *d* being made with a tapered head, and by turning it in, the two halves are forced apart.

The die stock, Fig. 31, is provided with a thumbscrew that grips the die when in place. The lower part *c*, Fig. 30 (*b*), of this die is bored out to the exact size of the rod to be threaded,

and forms a guide for the die in starting. These dies require some pressure to start them, but once started they cut a full thread at one operation. The large sizes are made with inserted chasers that are adjustable for wear and if broken may easily be replaced.

50. Pipework.—Pipework enters largely into some branches of machine work, and a few of the principal tools used in this connection will be illustrated and described. Pipe is made in lengths of from 15 to 20 feet. It is threaded on both ends at the pipe mill, and a sleeve screwed on one end. Large pipe has a ring screwed on the other end, to protect the threads during shipment and handling.

51. Cutting Pipe.—Large pipe is generally cut into the proper lengths in a pipe-cutting machine by a cutting-off tool, in the same manner that stock is cut off in the lathe, and afterwards is threaded in the same machine. Some pipe machines are driven by hand, others by power. A great deal of small pipe is cut with a pipe cutter, shown in Fig. 32. The body *c* of this tool carries a slide *e*, operated by the screw on the handle *f*. Three hardened-steel cutting wheels *a*, *b*, *d* are set in the frame and slide. The slide *e* is



FIG. 32.

drawn back by means of the screw, to allow the pipe to go in between the cutters, which are then forced into the pipe by turning the handle, and at the same time rotating the tool around the pipe. Other cutters of this sort are made that have but one cutting wheel, which is in the slide. A hack saw makes a good pipe cutter, if used carefully, and by using blades having 25 teeth per inch there is little danger of breakage. Thin brass and copper tubing can be cut easier by a hack saw than by any other means.

52. Threading Pipe.—When the pipe is cut to the correct length, it must be threaded. This is done, as has been said, in power-driven machines for the large sizes, but most of the small-pipe threading is done by hand with one of the various forms of pipe dies.

53. Pipe Stock.—The ordinary pipe stock is shown in Fig. 33. This stock has a body *d* into which handles *b*, *c*

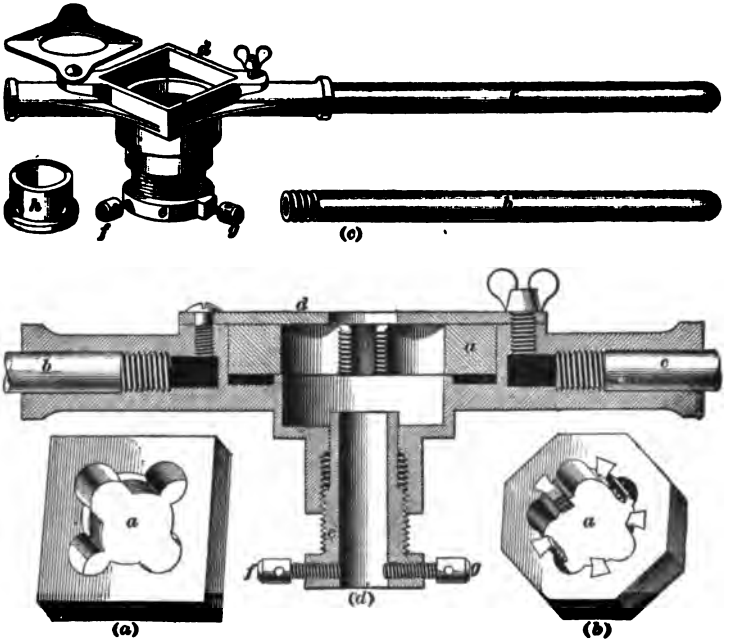


FIG. 33.

are screwed at each end. It has a square recess *d*, Fig. 33 (*c*), in the top to hold the die *a*, Fig. 33 (*a*). A cover *d*, Fig. 33 (*d*), slides over the die to hold it in place. For threading the larger sizes of pipe, the pipe stock is threaded internally and the bushing *e*, Fig. 33 (*d*), is screwed into it. The thread is $11\frac{1}{2}$ per inch for sizes up to and including 2 inches, and above that 8 per inch, to correspond to the standard pipe threads. A bushing, or thimble, *h* having a

hole through it of the size of the outside diameter of the pipe is placed in the bushing *e*, and the whole slid over the end of the pipe so that the cutting edges of the die rest on the end of the pipe. The bushing *e* is made fast to the pipe by a setscrew *f* and *g* and the stock given a few turns to start the die on the pipe, the screw thread in the stock acting the same as the lead screw in a lathe. As soon as the die has a good start, the setscrew holding the feeding screw may be loosened, and the work finished without it. The small sizes of pipe are threaded in the same manner, but the die stock is made without the feed or lead screw.

54. Adjustable Die.—This is made in two parts, as shown in Fig. 34. The stock is provided with the usual handles for turning and the thimble for guiding the dies on the pipe. The dies *a* are held in the stock *b* by means of the clamp screws *c*, and are made to cut larger or smaller

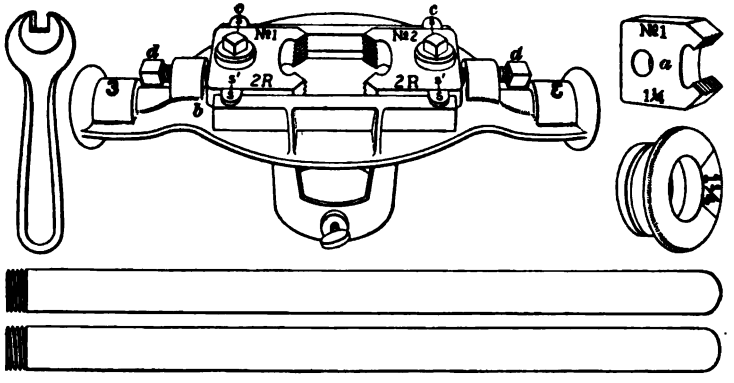


FIG. 34.

than the standard by the adjusting screws *d*. Lines *s* are cut in the stock, and corresponding lines *s'* are placed on each die, so that when these lines coincide the dies are set to cut pipe to the standard size. These dies are more easily sharpened than are the solid ones, which makes them decidedly superior.

PIPE VISES AND WRENCHES.

55. Pipe Vises.—Pipe, being round, cannot be screwed together by the ordinary forms of wrenches, and, being hollow, it cannot be held in the ordinary vise without being crushed. For cutting, threading, or having fittings screwed on, pipe may be held in a pipe vise, Fig. 10, Part 1, or in an ordinary vise having clamps made in the form shown in

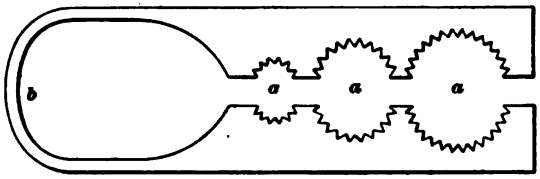


FIG. 35.

Fig. 35. The holes *a* in this clamp are made to fit the outside diameter of the pipe, and have teeth cut in them to prevent the work from slipping. They are held together by the spring *b*. For putting polished pipe together, some form of clamp or wrench having smooth jaws must be used.

56. Pipe Tongs. — Ordinary iron pipe is screwed together with wrenches of various forms. The principal ones are shown in the following illustrations: Fig. 36 shows

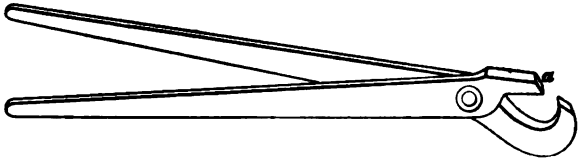


FIG. 36.

the most common form, commonly called *pipe tongs*, one size being provided for each separate size of pipe. This general style is also made with the jaw *a* adjustable and controlled by a screw, so as to adapt one pair of tongs to several sizes of pipe.

The chain tongs shown in Fig. 37 is especially adapted to work on large pipe. The handle *e* has two steel jaws *a* cut on both sides. A chain *b* made fast to the bolt *c* permits both sides of the jaws to be used. Wrenches of this

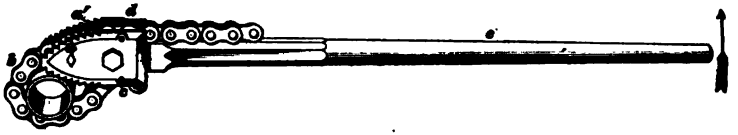


FIG. 37.

type are made of various sizes for use on all sizes of pipe. Chain tongs are the most rapid and economical tools of their kind for medium and large work.

57. Pipe Wrenches.—The Stillson pipe wrench, illustrated in Fig. 38, is an adjustable wrench. It has a movable jaw *a* moved by the milled nut *b*, and may be used on

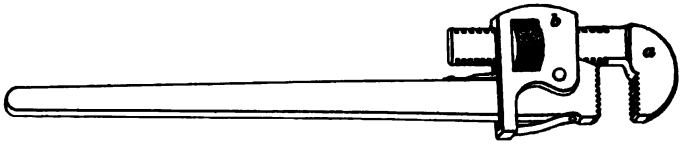


FIG. 38.

several sizes. It is made particularly for pipework, but finds many other useful applications. Alligator wrenches have a V-shaped opening in one end, and in the smaller sizes in both ends. One side of this opening is left smooth and the

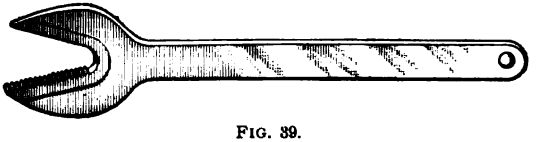


FIG. 39.

other has teeth cut across it in the form shown in Fig. 39. These wrenches grip all round objects, and are used to grip pipe in places where the other forms of wrenches can get no hold at all.

A wedge-shaped piece of steel, as *b*, Fig. 40, having teeth cut on it similar to those on the jaw of an alligator wrench, may be made for any size of monkeywrench. The jaw may be made in the form of a fork, the two arms of which reach past the bar of the wrench and have a hole through their ends, so that a split pin can be put through them to keep the jaw from falling from its place on the bar.

Fig. 40 (*a*) shows a monkeywrench having a manufactured jaw *b* on its bar. This jaw differs from the shop-made jaw in having only one arm, which is bent at right angles to

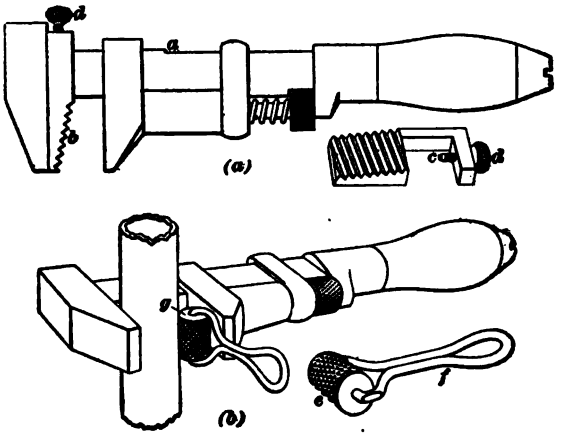


FIG. 40.

pass over or around the back of the bar, as shown at *c*. A thumbscrew *d* is used in this jaw, instead of the pin, to hold it on the bar.

Fig. 40 (*b*) shows a simple attachment for adapting a monkeywrench to pipework. This consists of a nurled and hardened cylinder, or roller *e*, having a wire handle *f* for convenience in putting it in place. It is placed between the wrench jaw and the pipe, or other round piece, as shown at *g*. A piece of 10-inch or 12-inch round file about 1 or 1½ inches long may be used instead of this attachment.

58. Use of Rope as Pipe Wrench.—A rope may be used in place of a pipe wrench, if a suitable wrench or tongs

is not available. The manner of making and using such a device is shown in Fig. 41. The rope is first doubled, as shown at *a*, and given enough turns round the pipe to insure gripping. A bar or even a piece of wood *b* is thrust through the double end of the rope *a*, and the two loose ends of the

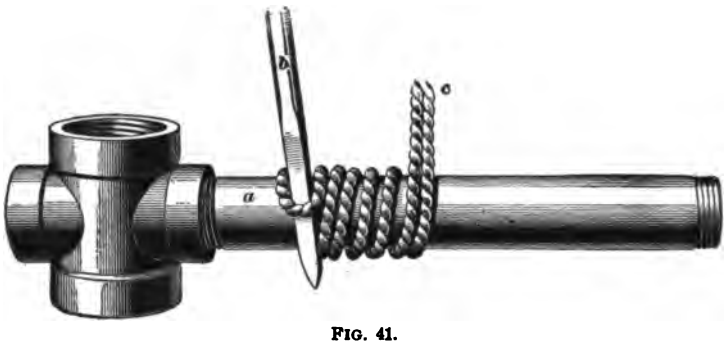


FIG. 41.

rope are brought together and held, as shown at *c*. Enough strain is put on *c* to prevent slipping, and the pipe is turned by the bar *b*, the same as with any pipe wrench. The workman may walk around the pipe, or by slacking off on both the bar and the rope ends, he may rotate the rope backwards to get a new hold.

LAYING OUT.

INTRODUCTORY.

59. Definition.—Laying out is the process of placing such lines on castings, forgings, or partially finished surfaces as will designate the exact location and nature of the operations specified in the drawing.

60. Preliminary Operations.—In many cases, one or more men are regularly employed in laying out work. Occasionally, the same men devote a part of their time to inspecting or testing finished or partly finished work. The

object of inspecting when partly finished is to prevent additional work, should the first operation be defective to a degree that calls for the rejection of the piece. One great advantage of having the work laid out by an expert who has the drawing of the finished piece before him is that he may determine, before any work is done, whether the forging or casting has the required amount of stock, and should there be insufficient stock at any particular point, the piece may either be rejected or perhaps saved by carefully locating the lines so as to permit the finishing of all the holes and surfaces; whereas, if a part of the work is done without the special laying out, it may afterwards be found that there is not sufficient stock for some later operation.

61. Most Economical Method.—The economy of having the laying out done by men set apart for that purpose is due to several reasons. Men become expert and quick at this kind of work; the tools of the shop are not idle while the men running them stop the machine to do the laying out, as was formerly the case; even the vise hands are saved the time of laying out their work; besides, it can be done on a convenient plate with proper tools to better advantage than otherwise. Then, work can be laid out as soon as the castings or forgings come into the shop, perhaps long before the tools are at liberty to finish the work, and it may be of great advantage to find out early any lack of stock, or any defect that may cause the rejection of the piece, or any change that is to be made, if it is a forging. For instance, a casting may appear to be all right, but a hole may be cored too large, or the core may not have been set correctly, or it may have moved in the mold. After laying out some of the lines and making sure that there is stock enough for finishing, it is often advisable to do part of the finishing before completing the laying out.

62. Divisions of Laying Out.—Laying out may be divided into two parts: the preliminary and the final. The preliminary laying out consists in measuring the piece to see that it is of the proper size and dimensions, and then

drawing such lines on its surface as will show where the first machining operations are to be performed. The center lines are so placed, if possible, that they will not be removed by the machining process, and can be used in resetting the piece for future machining. The final laying out consists of placing such lines on the machined surfaces as will indicate the further operations to be performed.

The preliminary laying out in the case of a steam-chest cover would be to level it on the table and draw such lines on its edges as will indicate its thickness; after which it should go to the planer and be machined to the dimensions denoted by the lines. The final laying out will consist of laying out the holes for the studs and such other operations as may be designated on the drawing.

63. Methods of Laying Out.—Laying out is done in different ways, according to the nature of the work and the accuracy required. The lines are drawn on the surfaces with surface gauges or scribers, and centers are denoted by prick-punch marks. Circles and arcs of circles are drawn with dividers and trammels, and many irregular forms are drawn on the work from accurately filed templets.

In some cases, the work is laid out by simply drawing the necessary lines on its surface. In other instances, permanence is given the lines by dotting them with prick-punch marks placed directly on the line; or, a thin chisel may be driven into the work on the lines, making a deep cut in the metal. Guard lines are often placed on the work to make sure that the original lines were closely followed, as, in laying out holes to be drilled, some machinists place a circle $\frac{1}{16}$ inch outside the one worked to, and if the hole is correctly drilled, it will be concentric with this circle.

64. Coatings on Which to Make Lines.—In many cases it would be impossible to scratch lines on an iron surface, especially when the latter surface is not perfectly smooth or when it is very hard. This has led to the use of various coatings, on which the lines may be made or in which they may be scratched. Sometimes, chalk is simply rubbed

on the surface. In other cases, powdered chalk is mixed with alcohol and applied with a brush, or whiting is mixed with alcohol or water and applied in the same way. Alcohol has the advantage over water in that it will dry quicker and has no tendency to rust the surface.

When the surface has been machined and is fairly smooth, it may be copper-plated by wetting and rubbing the surface with a piece of copper sulphate (blue vitriol), or, better still, by making a saturated solution of copper sulphate and applying this with a brush or swab. As the solution dries, it will be noticed that the surface is covered with a thin layer of copper. This cannot be done if there is any oil on the surface, and surfaces to be thus coppered must be cleaned perfectly before applying the solution. Lines may easily be scratched in this copper and will show very plainly on account of the difference in color between the iron and the copper. In some cases, a light coat of some quick-drying white paint is used, as, for instance, white lead and turpentine. In any case, after the lines are drawn, their location should be permanently established by means of light prick-punch marks.

LAYING-OUT TOOLS.

65. Tools and Appliances Used in Laying Out. A variety of tools are used in laying out work. The most common are the surface gauge, scriber, hammer, prick punch, level, square, dividers, trammels, and a line, if large work is handled. In addition to these tools, there should be a supply of quick-drying white paint, chalk, a solution of blue vitriol, a lot of iron wedges, and small pieces of sheet metal of various thicknesses for blocking, parallels of various sizes, small screw jacks, one or more pairs of V blocks, a pinch bar, and a hack saw.

The surface of the laying-out table or plate must be kept as clean as possible; therefore, a bench brush should be provided for the table, and for the large plate, a brush and broom. As a good many drawings are used at the laying-out table, a table or stand of sufficient size to hold them,

and drawers in which to place those not in constant use, should be provided near at hand.

66. Surface Plates.—The surface plate is used in machine construction for testing flat surfaces. It is generally made, as shown in Fig. 42, of a hard, close-grained iron casting having a flat top *a*, Fig. 42 (*a*), supported by a ribbed back *b*, Fig. 42 (*b*). Three legs *c*, *d*, and *e*, Fig. 42 (*b*),

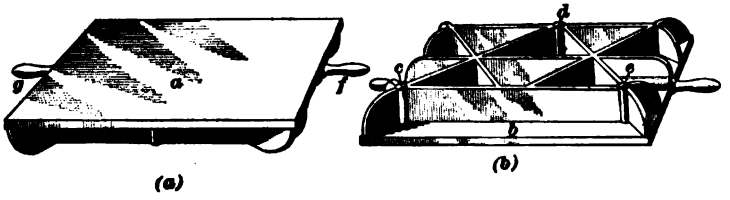


FIG. 42.

are provided, so that the plate will stand evenly on any surface. Handles *f* and *g* are placed on the ends, by which the plate may be lifted. The tops of these plates are first planed as smooth as possible, after which they are filed and scraped perfectly flat.

When in use, the surface plate is coated lightly with some marking material, after which the plate is rubbed over the surface that is to be trued. The marking material is left on the high places, thus showing the parts that are to be removed with the scraper. This operation is repeated until the surface shows a good bearing at all points. Small articles are rubbed on the plate. Care should be taken in using surface plates to use every part of the surface as evenly as possible, for if the work is all done in one place, the plate will soon be spoiled. Surface plates of this form are made in a great variety of sizes for different kinds of work. Special plates are often made for special work, in places where it is impossible to put a plate having a ribbed back.

67. Straightedges.—A straightedge is used for testing flat surfaces and the alinement of machine parts. Most

straightedges are made with two edges that must be straight and parallel. The metal of the straightedge must be so placed as to give the greatest stiffness in the direction of the edge to be used. For this reason, straightedges are usually made deeper than they are wide. Straightedges are made in a large variety of forms and lengths, and may vary from 1 inch or so in length up to 10 feet or more.

For small work, a graduated steel rule is frequently used as a straightedge, the hardened and ground ones produced by several manufacturers being the best for this purpose. Hardened-steel straightedges having the general form of a knife, so as to reduce the straightedge to a narrow line, are frequently used. Fig. 43 illustrates a common form that is hollowed out on the sides so as to give a better grip to the hand in using it.

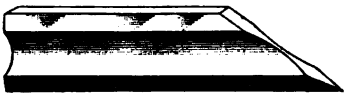


FIG. 43.

68. Long Straightedges.—Where straightedges of considerable length are desired, careful attention should be paid to their design, to see that they are made as stiff as possible, and at the same time that the weight is not unduly increased. Where only one straight surface is required, the form shown in Fig. 44 is very good indeed. These are made of cast iron, and the surface *a b* is carefully planed and scraped

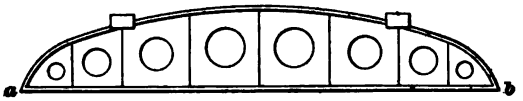


FIG. 44.

true. Where it is necessary to use a level on the back of the straightedge, or where other straightedges may have to be placed at right angles, it becomes necessary to have both edges true and parallel. For this class of work the tool shown in Fig. 45 is especially useful. The drawing shows the proportions for a 10-foot straightedge. It will be noticed that the general form is that of a box girder, and that the

center is cored out, openings being left in the sides to support the core during casting. The metal, in the case of a 10-foot straightedge, should be about $\frac{1}{2}$ inch thick, and a



FIG. 45.

straightedge of this form should be planed all over and allowed to season some time before it is finished, so as to relieve the casting strains as much as possible.

SUBDIVIDING CIRCLES.

69. Locating the Centers of Circles.—When it is necessary to draw a circle, on work where the center does not occur on the casting, but in the center of an opening or cored hole, it is necessary to locate the center from which the circle may be drawn. This may be done by fitting a strip of wood across the cored opening, and locating the center on this. Owing to the fact that wood is too soft to give a good center to work from, it is usual to place a piece of metal where the center is required. This piece of metal may be a tack driven into the wood, the center being located on the head; or it may be a triangular piece of tin having the corners bent at right angles to the surface, so that they can be driven into the wood, the center being located on the flat surface of the tin.

70. Use of Screw Jacks.—Sometimes, small screw jacks having flat sides on the body of the jack are used to locate centers, the screw jack being placed across the hole and the center located on its side, as shown in Fig. 46 (*a*). After the center is located, the bolt-hole circle is drawn, and the required holes spaced off on it. If the cored hole is too large for one screw jack to reach across, two screw jacks

may be placed with their bases together, as shown in Fig. 46 (*b*), and the center located on them.

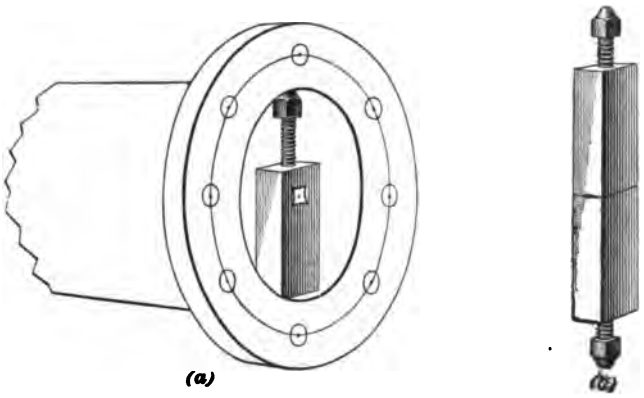


FIG. 46.

71. Laying Off Subdivisions of a Circle.—In case a circle is to be divided into 4 or 6 parts, or into multiples of 4 or 6 parts, it is usual to draw diameters dividing it into this number of parts first, and then make any additional subdivisions from these points. Four divisions can be easily obtained by drawing two diameters at right angles, the work being mounted on the laying-out plate, the horizontal diameter being obtained with the surface gauge, and the vertical one by means of a square.

To produce 6 divisions, it is only necessary to set the dividers to the radius of the circle and then step them around the circumference of the circle, when it will be found that the radius will just step around 6 times. In order to produce any other number of divisions, up to and including 100, the accompanying table is given. By its use, the dividers may be set very closely, and much of the time and trouble usually spent in getting the dividers properly set by stepping them around with trial distances may be avoided. The numbers in the column headed "N" indicate the number of divisions into which the circle is to be divided, and the numbers in the column headed "S" are the sines of

TABLE FOR DIVIDING CIRCLES.

N	S	N	S	N	S	N	S
1		26	.120540	51	.061560	76	.041325
2		27	.116090	52	.060379	77	.040788
3	.86603	28	.111970	53	.059240	78	.040267
4	.70711	29	.108120	54	.058115	79	.039757
5	.58779	30	.104530	55	.057090	80	.039260
6	.50000	31	.101170	56	.056071	81	.038775
7	.43388	32	.098018	57	.055089	82	.038303
8	.38268	33	.095056	58	.054139	83	.037841
9	.34202	34	.092269	59	.053222	84	.037391
10	.30902	35	.089640	60	.052336	85	.036953
11	.28173	36	.087156	61	.051478	86	.036522
12	.25882	37	.084804	62	.050649	87	.036103
13	.23932	38	.082580	63	.049845	88	.035692
14	.22252	39	.080466	64	.049068	89	.035291
15	.20791	40	.078460	65	.048312	90	.034899
16	.19509	41	.076549	66	.047582	91	.034516
17	.18375	42	.074731	67	.046872	92	.034141
18	.17365	43	.072995	68	.046184	93	.033774
19	.16460	44	.071339	69	.045515	94	.033415
20	.15643	45	.069756	70	.044865	95	.033064
21	.14904	46	.068243	71	.044232	96	.032719
22	.14232	47	.066793	72	.043619	97	.032381
23	.13617	48	.065401	73	.043022	98	.032051
24	.13053	49	.064073	74	.042441	99	.031728
25	.12533	50	.062791	75	.041875	100	.031411

half the angles obtained by dividing the circle into the number of parts given in N. The distance between any two points on the circle may be obtained by the formula $M = S \times D$, in which M equals the measured distance between two of the points in inches, D the diameter of the circle in inches, and S the number found in the column S of the table opposite the number of holes required.

EXAMPLE.—If it is required to divide a 62-inch circle into 44 equal parts, what will be the distance to which the dividers should be set?

SOLUTION.—Opposite 44 in the column marked N of the table, and in the column marked S, is found .071839. Substituting in the formula, we have

$$M = .071839 \times 62 = 4.423018 \text{ in.} \quad \text{Ans.}$$

For ordinary work it would not be necessary to set the dividers closer than to hundredths of an inch; hence, the dividers may be set to 4.42 inches. On account of the fact that 44 is divisible by 4, the circle may be divided by two diameters drawn at right angles, and the spaces marked off to the four points thus obtained.

72. Laying Out the Square and Hexagon.—It is always best in laying off a circle to locate either 4 or 6 points accurately and to work from these, as this reduces the effect produced by means of a slight mistake in the setting of the dividers; for if the circle were all laid off from one point, and the dividers were set to a distance slightly greater than that required, the last division would be smaller than the others by an amount equal to this error multiplied by the number of spaces in the circle. But by dividing the circle into 4 or 6 parts, and then stepping off the spaces each way from each of these points, the total error at any given point will only amount to the error in setting the dividers multiplied by the number of spaces marked off from the given point, which will be from $\frac{1}{8}$ to $\frac{1}{12}$ of that in the previous case, depending on whether the circle has been divided into 4 or 6 parts.

LAYING-OUT PLATES.

73. Plate for Light Work.—For laying out light or small work, the size and character of the plate used may vary greatly. In some cases a flat casting, as the base of an old machine, is taken from the scrap pile and planed up; this is placed on a bench or on suitable trestles. In other cases, a well-designed casting is made. Fig. 47 illustrates a general form of laying-out plate. The plate *a* may vary in size from 2 or 3 feet on each side up to considerable

size, about 7 feet by 10 feet being the largest size practicable for this design of plate. In the larger size, the top *a* should be made 1¼ inches thick, the ribs *b* should be carried around the sides of the plate and cross-ribs placed across the back of the plate about every 24 inches; the depth of these ribs for a plate 7 feet by 10 feet should not be less than 8 inches, and they should be of the same thickness as the body of the plate. The casting should be planed on the upper surface *a* and on the faces of the ribs *b*, so that the faces *b* will be at right angles to the surface *a*, thus making it possible to use surface gauges or other tools from the faces *b*. In a plate

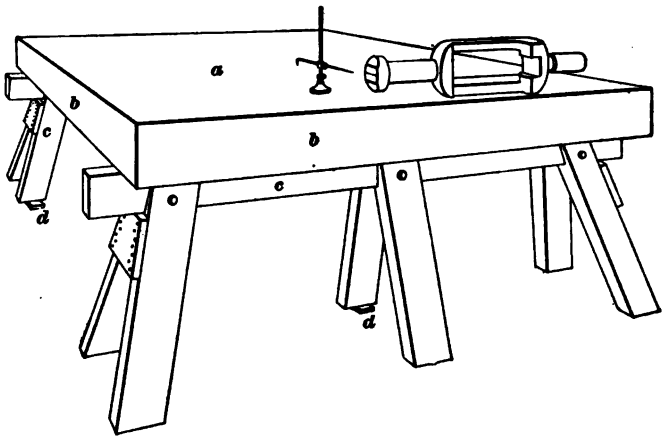


FIG. 47.

of this style, it is well to draw parallel lines both lengthwise and crosswise of the plate, the lines being 3 or 6 inches apart. As shown in the illustration, the plate is mounted on trestles *c*, and care should be taken to keep the upper surface of the plate level and out of wind, by adjusting wedges under the legs of the trestles, as shown at *d*. For ordinary working, it is well to have the upper surface of the plate about 30 inches from the floor. Such a plate as this may be placed under the main traveling crane, and it is also well to have an auxiliary air lift, or similar hoisting device, for handling the work when the crane is not available.

74. The advantages of this style of plate are that it is not a permanent fixture in any one place, and hence can be easily moved from one part of the shop to another, if it should be more advantageous to have it in a different position. Then, too, if the plate is not needed for some time, but the floor space is, it can be turned up on one edge and set against the wall, and the space that it formerly occupied utilized for erecting or for other work.

75. The disadvantages of this style of plate are that owing to its support on trestles it is not suitable for laying off heavy work that requires great accuracy, on account of the fact that it is impossible to keep the plate true and out of wind when heavy weights are being placed on or taken from it, as the stresses on both the plate and the trestles are constantly changing. Sometimes, a plate of this general style is mounted on a concrete or brick foundation, but if the latter expense is to be incurred, it is usually best to have a more elaborate one, such as is described in Arts. **76** and **77.**

76. Plate for Heavy Work.—For laying off heavy work, the plate must have a very firm foundation, and the ribs must be of such a depth that there is no danger of the plate springing under the weight of the piece being laid off. Plates for heavy work are usually made lower than those for light work, the top of the plate being placed from 18 to 24 inches above the floor. Fig. 48 illustrates a very good plate for heavy work that is in use in one large shop. The top of this plate is 24 inches above the floor, and it is composed of two pieces *A* and *B* that are joined together with a tongue and groove, as shown at *C*. This plate is 8 feet by 15 feet, and the ribs around the outside and along the center are made to extend clear to the foundation, which is only 2 inches above the floor, thus making the plate 22 inches deep. Parallel grooves 6 inches apart are planed the entire length of the top surface, and at right angles to these lines are ruled on the surface 6 inches apart. The grooves are especially handy, on account of the fact that

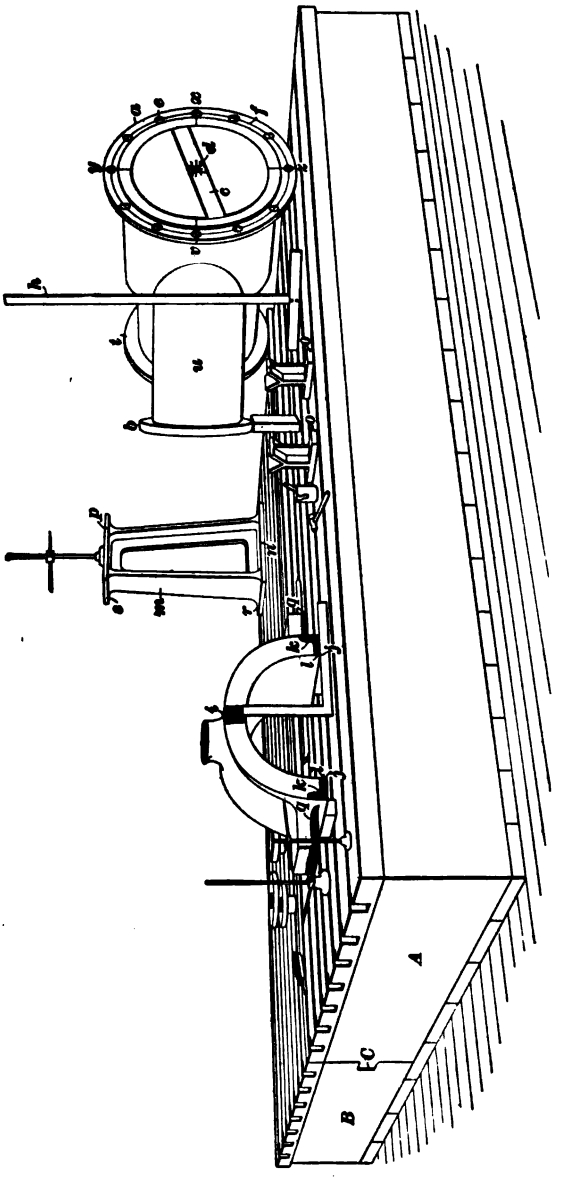


FIG. 48.

parallels can be slipped into them and pieces brought against these parallels for lining up, after which measurements may be made from either grooves or lines. In the case of all heavy plates, care should be taken to see that the plate has a good bearing on the foundation, and that the foundation is made deep and strong enough that it will not settle or be broken under any weight that is liable to be put on the plate.

77. Plate for General Work. — In shops handling a variety of work, varying from heavy to light, a plate of

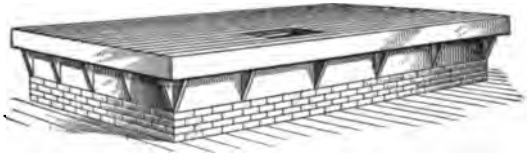


FIG. 49.

the form illustrated in Fig. 49 may be used. This plate is about 8 feet by 12 feet, and the details are shown in Fig. 50.

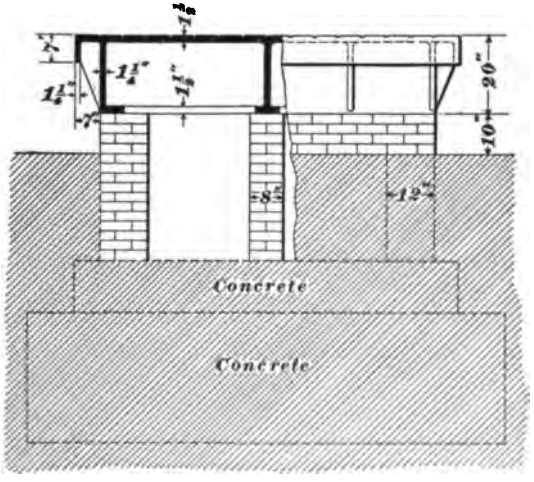


FIG. 50.

The foundation consists of a concrete base on which are built three brick walls running lengthwise of the plate and

a cross-wall at each end. The plate is supported on these walls, as shown in Fig. 50. A hole in the plate, at least 18 inches by 24 inches, together with an opening in the middle wall, affords access to the space beneath the plate for the purpose of cementing between the iron and brickwork. This hole in the plate is also useful, on account of the fact that it permits parts of the work to hang below the surface; as, for instance, one crank of a three-throw crank, or an arm on a rocker-shaft. The hole is cast with a ledge to receive a wooden cover. This cover is necessary to prevent objects from falling through the hole and being lost under the plate. The top of the wooden cover should be $\frac{1}{8}$ inch below the surface of the plate. It will be noticed that the plate overhangs the foundation 7 inches all around, to allow foot-room on the floor.

Grooves $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch deep are planed lengthwise every 6 inches, and lines made crosswise every 6 inches; or grooves may be planed both lengthwise and crosswise. A number of short parallels $\frac{1}{2}$ inch square should be provided to drop into the grooves to aid in locating the work or tools. The proportions or size of the plate may, of course, be varied to suit the character of the work being done. It is not good practice to mount a plate on brick walls all running in one direction, when heavy work is to be placed on or taken off the plate; for if work were to strike the end, there would be danger of racking the walls, while the tying of the longitudinal walls together at the ends tends to overcome this difficulty, and also prevents dirt from collecting beneath the plate.

78. Revolving Laying-Out Plate.—In many cases it is quite important to have the light fall on the work from a certain direction, so as to enable the operator to see the lines being drawn, and also in the case of small work, it is often necessary to operate on several sides of the piece. If this work were placed on a large plate, the work would have to be turned and reset several times, or the operator would have to climb around over the plate. To overcome

this difficulty, a plate of the general form shown in Fig. 51 may be employed. This consists of a circular table *a*

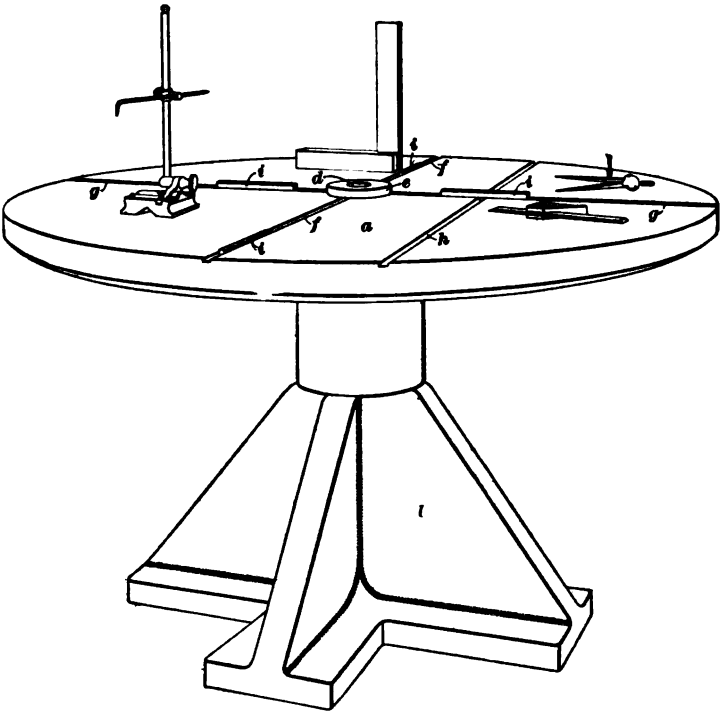


FIG. 51.

mounted on a suitable foot, or base, *b*. The back of the plate *a* is ribbed, as shown in Fig. 52, and a ball bearing is inserted between the plate *a* and the base *b*, as shown at *c*.

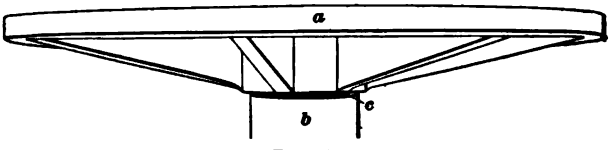


FIG. 52.

In order to facilitate the centering of work having a hole in it, a plug *d*, Fig. 51, may be inserted in the center of the

table and a ring *e* of suitable diameter placed over the plug. Work thus dropped over a ring of the proper size can be quickly centered. To facilitate the dividing of work, two grooves *f* and *g* are planed across the table at right angles. These grooves are so located that one edge of the groove passes through the center of the table. For convenience in measuring, other grooves may be located at any specified distances from the center, and parallel to either one of the main grooves, as shown at *h*. Small parallels are introduced into the grooves for adjusting squares or other tools, or to bring the work into the desired position. These parallels are shown in position at *i*, *i*. By means of these two grooves and the parallels, work can very quickly be divided into four equal parts by dropping the parallels into the grooves, and bringing a square against the sides of the parallels in contact with the edges of the grooves that pass through the center of the plate. The top of the table illustrated is 31 inches above the floor, and the rim is 2 inches thick. For some classes of work it is convenient to have circular lines, 1 inch apart, turned on the table before the plate is taken from the lathe.

This form of table can be easily taken to the work, in place of bringing the work to the table, in cases where there is a large amount to be handled, and especially when it is advantageous to have it done near the same machine. For convenience in moving the table, an extension of the hole that receives the pin *d* in the base *b* may be tapped, and a strong eyebolt fitted to it. This bolt will form a ready means of attaching the crane hook to the table.

79. Special Laying-Out Appliances.—On the laying-out table illustrated in Fig. 48 are shown several special laying-out appliances. First may be mentioned the parallel shown at *m*. These parallels are made in various heights, differing by even feet, and smaller solid parallels or hollow rectangular parallels are made, varying by inches, so that any height, varying by inches, can be obtained from a series of them. The edges *n* and *p*, and *r* and *s* should be in the

same vertical planes, so that when one of the edges *n* or *r* is brought against a certain parallel or line on the plate, the corresponding edge *p* or *s* will be in the same vertical plane. This enables the man doing the work to obtain horizontal measurements from the edges of the upper surfaces of the parallels. With the use of these parallels, it is unnecessary to use the old-fashioned high surface gauge, which could never be depended on because of the spring of its parts.

At the front of the plate are shown two V blocks *o*, *o* that are extremely useful in laying out pieces having turned ends, or any form that has to be supported in this manner. At *h* is shown a special T square, which, for some classes of work, is more useful than an ordinary square for drawing vertical lines, owing to the fact that there is little, if any, danger of the portion in contact with the plate becoming displaced; while if an ordinary square were used, it would be necessary to make the arm or beam in contact with the plate very heavy to balance the long blade.

EXAMPLES OF LAYING OUT.

80. Laying Out Bolt Holes for Pipe Flanges. In Fig. 48 at the right-hand side of the plate is shown a casting for a branch pipe in which it is required to lay out bolt holes for the different flanges. The pipe is leveled by blocking up the small end *t* until the large end *a* stands square with the plate or table. The branch, or arm, *u* is next raised until the surface *b* is square with the table. Wooden strips are fitted across the ends of the pipe, as shown at *c*, this fitting usually being done before leveling up the pipe, so as not to displace the setting by driving in the wooden strips. After the wooden strips are in place and the pipe is leveled up, the trammels are set to approximately the radius of the circle *e* that has been turned on the end of the pipe while in the machine. With these trammels, the arcs at *d* are drawn and a center located between them. Usually, a small piece of tin or other metal is placed at the center of the wooden strip, to receive the center when located.

After this, trammels or dividers are set to the radius of the bolt circle *f* and this circle drawn. If the drawing calls for an even number of holes, a surface gauge is set to the center and a line drawn across the flange, as shown at *v x*. This line may be continued across all three of the flanges. If the number of holes is a multiple of 4, a vertical line is also drawn by means of a square, or a T square similar to that shown at *h*, thus locating the top and bottom holes *y* and *z*. The other holes are spaced off from these by means of dividers. In case of any number of holes, whether odd or even, the setting of the dividers can be obtained by the method described in Art. **71.** In the illustration, 12 holes are shown in the flange *a*. When the holes in the three flanges must have some fixed relation to one another, the horizontal line *v x* is carried around all three faces, and the holes laid off from this as required.

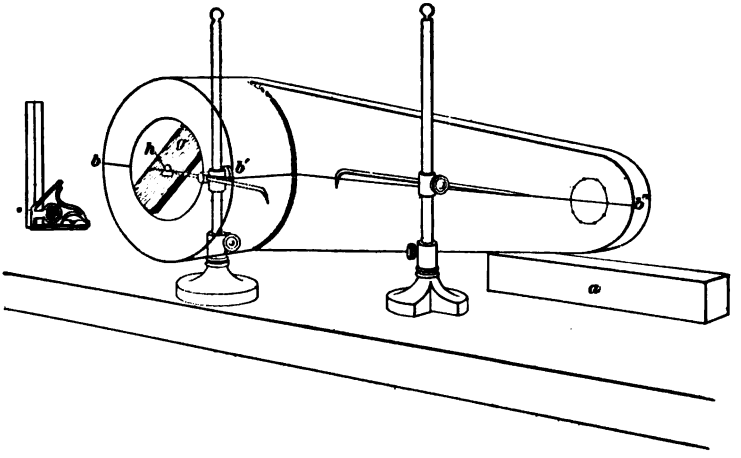


FIG. 53.

81. Laying Out a Large Journal Cap.—At the left-hand corner of the plate, Fig. 48, is shown a journal cap in the process of being laid off. The casting is blocked up on the plate so that the front and back faces are approximately square to the surface, and the center line *i* is drawn

midway between the points j, j. The shoulders k, k are laid off at equal distances from the center line i, and a proper allowance for finish is made at the top of the box, after which the lines l, l are drawn, so that the vertical distance from the horizontal plane passing through l, l to the point determined at the top of the box is equal to the radius of the finished box. The lines q, q on the flanges of the cap are next drawn the proper distance above the lines l, l. After this, the cap is planed before the holes for bolting down the cap are laid out or drilled.

82. Laying Out a Crank-Arm. — The crank-arm shown in Fig. 53 may be laid out as follows: The piece is first placed on its side, with the parallel a under the small

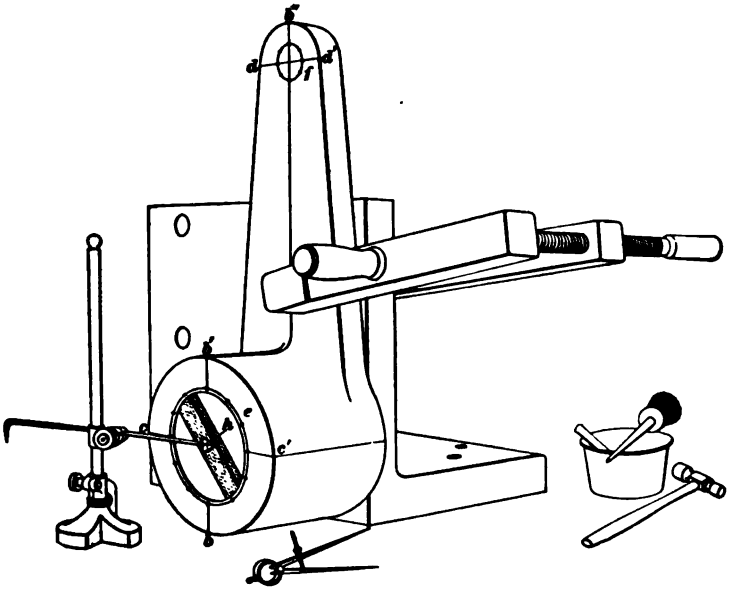


FIG 54.

end. A surface gauge is set to the center of the hub, which has been determined by placing a wooden strip g across the hub and locating a center h on it by means of dividers. After this, the parallel a is pushed under the end of the arm

until the small end is raised so that the point of the dividers is level with the center of the arm. Then the line *b b' b''* is drawn. After this the arm is clamped to an angle plate, as shown in Fig. 54, the line *b b'* being brought vertical by means of a square. The surface gauge is set to the center *h* and the line *c c'* drawn. The surface gauge is next set so that its point will be above the line *c c'* an amount equal to the distance between the two holes in the arm, and the line *d d'* is drawn. This locates the center of the hole *f*, after which the circles at *e* and *f* may be drawn with dividers and marked off with prick-punch marks, as shown, ready for drilling or boring.

83. Laying Out a Crosshead.—The method of laying out a crosshead is governed principally by the design of the crosshead. The form shown in Fig. 55 is one provided

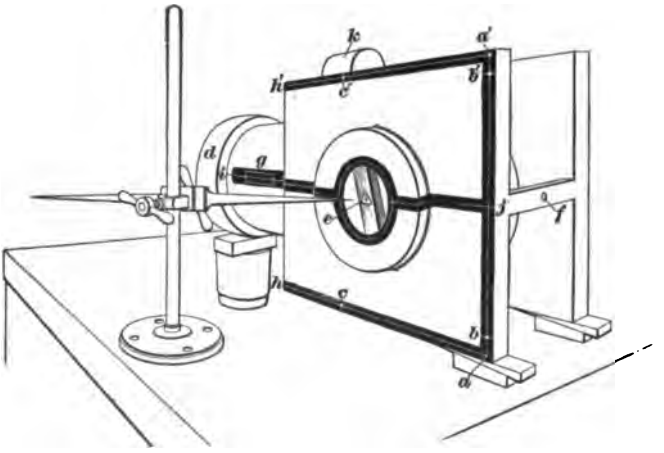


FIG. 55.

with adjustable shoes, the end *h h'* of the crosshead being considerably narrower than the end *a a'*, so that as the shoes are moved along on these inclined surfaces they will be expanded. The method of laying out is as follows: The crosshead is placed on the table, with blocking under the piston-rod end, and wedges under both sides of the connecting-rod end, as shown in the illustration. If the piston-rod end is

to be turned at the part marked *d*, the casting is usually made with a metal bridge *f*, which is cut out after the rest of the machine work has been done. In case no such metal bridge exists, it is necessary to insert a wooden strip at this point on which to locate the center *f*. Wooden blocks are also placed in the holes, as shown at *e*, and in the center of the piston-rod hole in the end *d*.

Chalk or white paint is applied in a broad line wherever the laying-off lines are to be placed, as shown by the broad, dark marks in the illustration. The centers of the holes for the connecting-rod pin and for the piston rod are now found, and the casting is leveled up by them and brought square with the table at the connecting-rod end. If it is found that the cored holes for the piston-rod or crosshead pin are not in the correct relative position, the body of the casting may be shifted somewhat, to bring them into such a location that all can be finished to the required dimensions. When these points are definitely located, the center line *ij* is drawn on all sides of the work. The centers at each end of the cross-head pinholes *e* are laid off the proper distance from the piston-rod end *d*, and a circle is drawn at each end of the cross-head pin. A circle is also drawn for the piston-rod hole. The slot *g* for the piston-rod key is next laid off the proper distance from the end *d*. This slot is sometimes made with round ends and sometimes with square ends, depending on the conditions specified in the drawing.

The line *a a'* is drawn the correct distance from the center *e*, this line being located by means of a square that is set on the table. The lines *a h* and *a' h'* are not parallel to the table, on account of the tapered form of the crosshead body, and in order to determine these lines, the following process may be used: The taper is usually given as so much per foot on the drawing, and this amount may be marked off from *a* and *a'*, as shown at *b* and *b'*. After this, short vertical lines are located at *c* and *c'*, 1 foot from the line *a a'*, and the surface gauge is set to the point *b*, and a mark made at *c*. It is then set to *b'*, and the mark made at *c'*, thus establishing two points on the inclined lines. After this

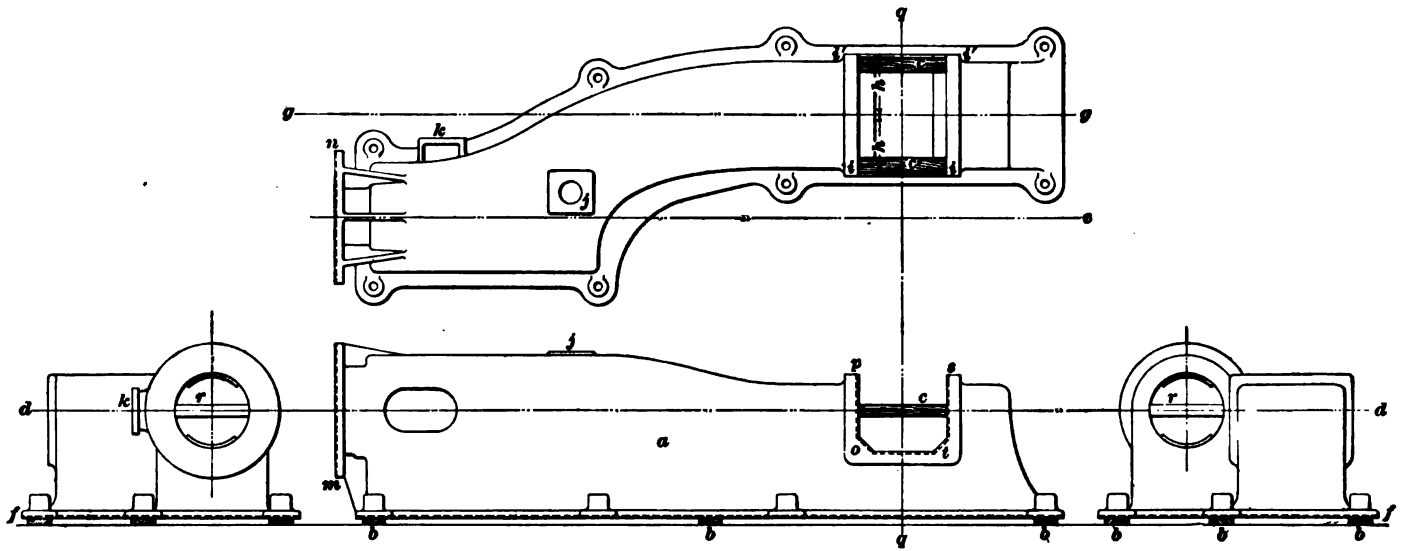


FIG. 56.

a straightedge may be laid through the points *a* and *c* and the line *a h* drawn, and then through the points *a' c'* and the line *a' h'* drawn. The lugs *k* must be drilled for screws to operate the crosshead shoes. These screw holes may be located by drawing horizontal lines on the piston-rod end of the lugs by means of the surface gauge. These lines must be the proper distance from the center line of the crosshead. After this, the center of the lugs may be found by means of dividers, and the circles representing the holes laid out.

84. Laying Out an Engine Bed.—The method of laying out an engine bed differs according to the type of bed, but the essential features of the process are the same. Usually, the work has to be done in two or three operations, owing to the fact that some of the surfaces have to be machined before the last part of the laying out can be done.

The bed chosen for illustration is shown in Fig. 56 and is of the solid cast variety, having bored guides, the bearing for the crank-shaft being cast solid with the bed, and the cylinder being arranged to bolt to the end of the bed. The bed casting *a* is placed on the laying-out or machine table, right side up, with blocks under it at intervals, as shown at *b*, *b*. Wooden strips are fitted across the ends of the guides, as shown at *r*, and across the sides of the jaws for the crank-shaft bearing, as shown at *c*. The centers of the guides are located on the wooden strips at both ends, and those of the jaws at both sides. The bed is now tested with the surface gauge, and set level by driving wedges between the bed and the blocks *b*. If either of the points located does not come true, the centers may be shifted slightly, care being taken to allow stock enough so that the guides and the jaws of the main bearing can be finished. Some beds of this type have their bottoms planed. If the bottom is not to be planed, it should be left as nearly parallel with the center line *d d* as possible. After having adjusted the centers of the guides and the jaws so that they all come level, and so that there is sufficient stock for finishing these parts, a surface gauge is set to the height of the center of the guides,

and the line *d d* is drawn on painted strips or spots on both sides and ends of the casting. If the bottom is to be planed, the line *f f* should be drawn parallel to *d d*, and at the proper distance from it. After this, the blocks *r*, *r* at the ends of the guides are removed, and a line (either a piece of piano wire or a sea-grass fish line) is stretched through the guides along the line *e e*. The distance from this line *e e* to the center of the crank-shaft bearing is measured, and the line *g g* established and marked off on the jaws of the bearing. Then the distances *h*, *h* are determined, and the lines *i i* and *i' i'* drawn so as to determine the amount of stock to be removed from each end of the bearing.

The height of the governor pad from the bottom of the bedplate is marked off at *j*, and the amount to be removed from the rocker-arm hub is laid off at *k*. After this, the end of the bed to which the cylinder is to be bolted is also laid off, the line *m n* being drawn, thus determining the amount to be faced from this end. The distance from the end of this face to the center of the bearing should agree with the drawing. It will next be necessary to machine most of the faces already determined, after which the lines *o p*, *s t*, and *o t* may be laid off on the jaws of the bearing, and the center of the rocker-shaft hub at *k* may be laid off the proper distance below the center line. After the guides are bored and the end faced off to the line *m n*, the bolt circle may be drawn on this end, and the bolt holes laid out in a manner similar to that described for the laying out of bolts and flanges, Art. **80**.

If the laying out is done on a table having lines running both lengthwise and crosswise, it will simplify matters to adjust the bed so that some one line corresponds with the center line *d d*, after which many of the measurements may be obtained from the other lines.

85. Gauges for Laying Out Key Seats. — Different types of gauges have been adopted for laying out key seats, but for the ordinary run of work the form shown in Fig. 57 will be found very useful. This consists of a ring

of cast iron *a* that is bored to the correct diameter *b*, and that has the necessary keyways laid out in it, as shown at *c* and *d*. This ring may be slipped over the shaft, and the keyways marked from it; it may then be removed and placed on a hub of the crank or wheel, and the keyways on it also marked out, thus insuring the accurate location of these keyways.

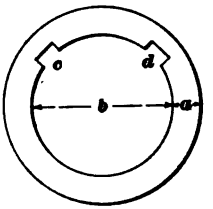


FIG. 57.

86. Laying Out Ends for Small Rods.—A convenient method of laying out the ends of small rods is shown in Fig. 58. In this, the piston rod *a* is placed on V blocks that bring it level. A stake or post *b* is put into a hole in the plate or table, to which it has been fitted, so that it stands perpendicular, as shown, with its upper end through

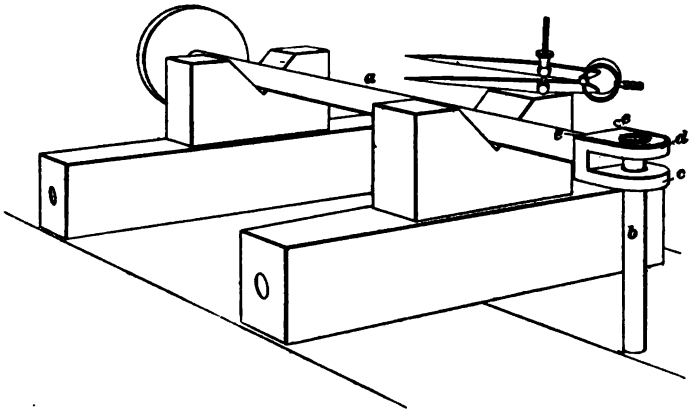


FIG. 58.

the holes in the fork *c*, fitting it accurately. The top end of the post *b* has a small center-punch mark in it, which provides a convenient center from which to draw the circle *d* for the rounded end of the fork. The parallel edge lines from *e* and *e* tangent to this circle are drawn by means of a surface gauge, after the fork has been revolved to a vertical position and set to a square.

ERECTING.

(PART 1.)

FLOOR WORK.

BLOCKING.

INTRODUCTION.

1. Definition.—The term **blocking** is applied to the various pieces of material that are employed for temporarily supporting work that is being done on the erecting floor or in the field. The purpose of the temporary supports is either the alining of the work in some particular direction or directions, or the raising of the work above a certain position in order to make it more accessible.

2. The form of the blocking depends on the character of the work for which it is to be used and the service it is intended to perform. In a great many cases the simplest form and the most elaborate form of blocking can be and are advantageously used alongside of each other on the same piece of work.

3. The simpler forms of blocking merely serve to support the work; while the more elaborate forms can, in addition, be employed for moving the work to an extent depending on their construction. Among the simpler forms of blocking may be mentioned *wooden blocks*, *trestles*, and *iron parallel blocks*. Trestles are known by the name of **horses** in many localities. *Screw jacks* and *stone jacks* are

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examples of the more elaborate forms of blocking, and *hydraulic jacks* are often used for lifting work, but not for blocking or holding it.

WOOD BLOCKING.

4. Wooden Blocks. — For supporting the heavier classes of work, either on the erecting floor or in the field, wooden blocks are extensively used. The blocks are generally made square; they may have a thickness that varies from 2 to 14 inches, and a length that varies from 2 to 6 feet or more. Pine and similar soft woods are often used for blocking, on account of their low price; there is no particular objection to the use of the softer woods for work done away from the shop, where the chances are that the blocking will not be in use for any great length of time. Hard wood is preferable for work on the erecting floor, since it will keep its shape better and last much longer than the softer woods.

5. Wooden blocks are sometimes used for packing blocks that are to be placed under the clamps that secure work to the table of a machine tool. When used for this purpose, it is recommended that hard wood which has been sawed square across the grain be used. The block should then be placed on end so that the grain is at right angles to the table, on account of the fact that wood is less easily compressed in the direction of its length than across the grain.



FIG. 1.

6. Trestles.—The trestle is used as a support for large, but comparatively light, work. It may be made as is shown in Fig. 1. The legs should be cut so as to leave a shoulder *a*, and should be bolted to the beam *b* by bolts passing through the legs and the beam. Lagscrews are often used instead

of through bolts, but their use for this purpose is not recommended. When great stiffness is desired, or when the weight to be supported is rather heavy, the legs may be tied together near the bottom by boards nailed across them. The only objection to this is that the trestles then cannot be stacked on top of one another when not in use. Trestles may be made of any convenient size; when they are used frequently they should be constructed of hard wood.

IRON BLOCKING.

7. Rectangular Iron Blocking.—The simplest and the most common forms of iron blocking are the solid parallel bars used in connection with machine tools. Large parallel bars, or **parallel blocks,** as they are often called, are usually made hollow, and are then well ribbed in order to safely carry the great weight often placed upon them.

8. Two excellent styles of parallel blocks are shown in Figs. 2 and 3. The block shown in Fig. 2 has a form that combines considerable strength with lightness. It is planed all over so that opposite sides are parallel and adjacent sides are at right angles. When a number of such blocks are made, it is advisable to make their corresponding dimensions equal, in order that the blocks may be used in pairs. The block shown in Fig. 2 is so constructed that a number of equal blocks may be piled up to suit the requirements of the work and then form practically a single block. Holes for dowel-pins are drilled in corresponding positions in the four faces of each block. The dowel-pins are made a good fit; they prevent the blocks from slipping on each other and at the same time permit them to be readily separated. One of the dowel-pins is shown at *a*.

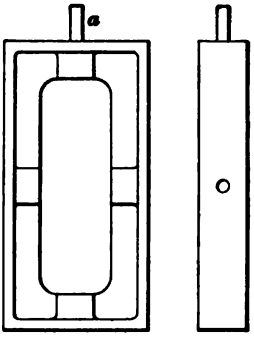


FIG. 2.

9. The block shown in Fig. 3 has the general form of a box; it is finished all over and is provided with **T** slots and **V** grooves, as shown. The **V** grooves in the sides permit the block to be used with either side up for round work; the

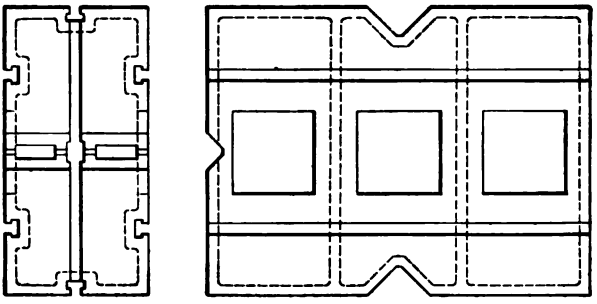


FIG. 3

T slots permit the work to be fastened to the block, or the block to be fastened in position by bolts. Blocks of this type may be used singly, or they may be piled up to any height that the work may require.

10. When making cast-iron parallel blocks, it is recommended that they be made in sets, in which all the blocks that are used together are exact duplicates. Blocks of different sizes may be made with a rectangular cross-section and with the short side of the large block equal to the long side of the next smaller size, and the long side of each from two to three times as long as the short side.

11. Cylindrical Iron Blocking.—A kind of blocking that is quite convenient for some classes of work, together with its application to a piece of work, is shown in Fig. 4. The blocking greatly resembles a short section of flanged cast-iron pipe; the sections may have the flanges strengthened by ribs, as, for instance, the sections *a*, *a*; or, the flanges may be plain, as those of the sections *b*, *b*. The flanges should be faced straight and parallel with each other, and the different sections should all have the same length.

12. A lighter form of pipe blocking is made of wrought iron or steel pipe that is threaded at both ends to receive flanges. The latter should be faced after they are screwed on the pipe.

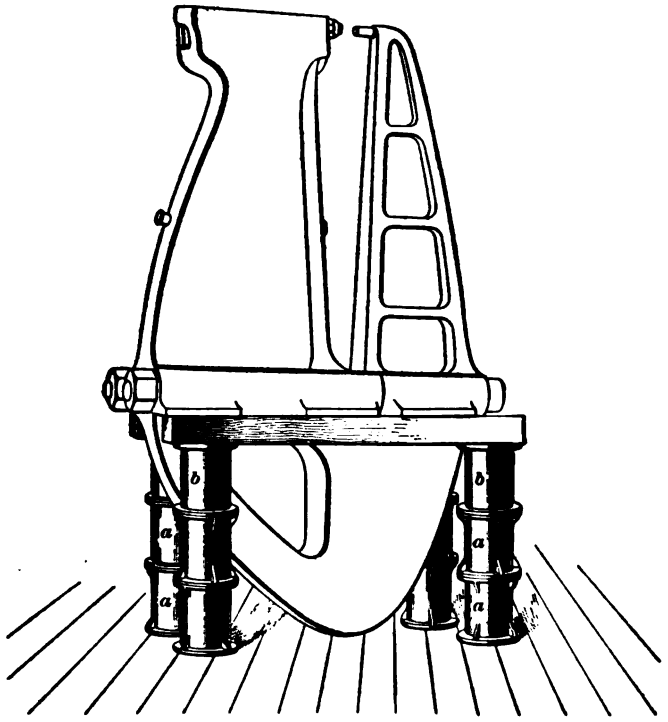


FIG. 4.

13. Adjustable Parallel Blocks. — The adjustable parallel block is illustrated in Fig. 5 (*a*). Its first cost is greater than that of ordinary parallel blocks, but it will be found both a time-saving and money-saving device on account of the fact that one adjustable parallel block displaces a number of the ordinary non-adjustable type. By far the greatest advantage of the adjustable parallel block lies in the fact that any thickness within the range of the block can be obtained. In other words, it can be adjusted exactly

to the requirements in any particular case. It consists of two separate pieces *a* and *b* that are movably connected together by a dovetail, which is clearly shown in the end view. After the two pieces have been carefully fitted together, the

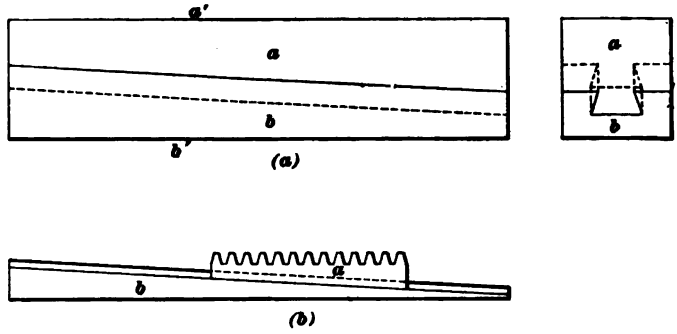


FIG. 5.

block is planed so that its surfaces are square with one another, and opposite surfaces are parallel. The dovetailed slide being at an angle to the surfaces *a'* and *b'*, the distances between these two surfaces may be varied by sliding the pieces upon each other. In order that the pieces may not slide under a heavy load, the inclination of the slide to the surfaces *a'* and *b'* should not exceed 10°.

14. An adjustable parallel block constructed as shown in Fig. 5 (*a*) may be made any convenient size and will be found a very useful appliance for the various machine tools. The block may be, and often is, used as a gauge by which to set a planer tool for planing work to an exact height above the planer or shaper table.

15. If the base *b* is extended to two and one-half times its ordinary length, as shown in Fig. 5 (*b*), and rack teeth are cut the whole length of *a*, a good gauge for getting the exact thickness of the racks used for various machine tools is obtained. The teeth in the part *a* are placed in mesh with the pinion and the part *b* is set so as to give just the right fit between the pinion and the rack seat. After the gauge is set, it may be removed; the pieces of rack, which

are generally left too thick, are now finished to the size indicated by the gauge. The pitch of the teeth cut in this gauge must, of course, be the same in every case as that of the pinion.

JACK-SCREWS AND HYDRAULIC JACKS.

16. Jacks.—In addition to the parallel blocks just described, the lifting device known as a **jack** is almost indispensable in all kinds of floor work, especially in erecting. Jacks are made in a large variety of styles and sizes, from those intended for leveling up light work on the tables of machine tools, to the heavy jack-screws and hydraulic jacks capable of raising or supporting 150 tons or more, and consequently are used for a wide range of work.

17. Simple Leveling Jack.—The simplest form of jack consists of a circular cast-iron foot, which is faced at the bottom and has a tapped hole through it. A square-headed screw with a slightly rounded top, as shown in Fig. 6, is used for raising the work. This style of a jack-screw is used principally in leveling up work on the tables of machine tools, although it will be seen later that jacks resembling this are sometimes made in large sizes and used in erecting.

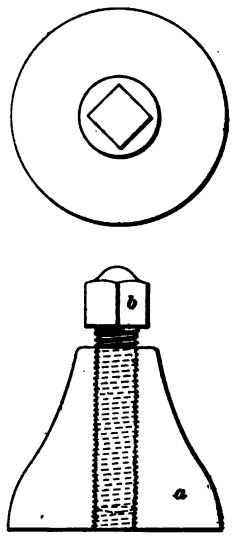


FIG. 6.

18. Adjustable-Top Leveling Jacks.—A good little case-hardened jack, with an adjustable cap, which is very serviceable for machine-tool work and light assembling, is shown in Fig. 7 (*a*). The body *a* is tapped to receive the adjusting screw *b*, which has a square top and holes for the rod *c*. The cap *d* is attached to the screw by a ball-and-socket joint, so as to permit the cap to accommodate itself to the angle of the work. When a solid or conical top

is more suitable for the work, a second screw *c* is substituted for *b*. The foot of the body *a* is counterbored to fit the

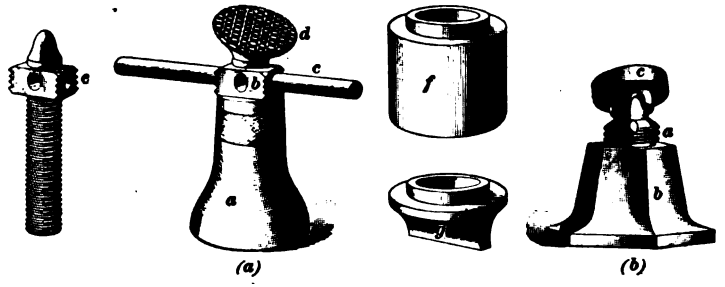


FIG. 7.

projection on the auxiliary base *f*, which may be placed under the jack when a greater height is required. Auxiliary bases of different heights may be used as needed. A special base *g* is also furnished with the jack and is used where this form of base is more suitable.

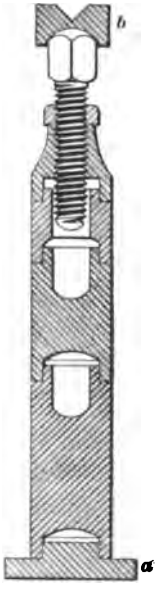


FIG. 8.

19. Another very serviceable jack for light erecting and for setting work on machine-tool tables is shown in Fig. 7 (*b*). A steel screw *a* having a square thread is screwed

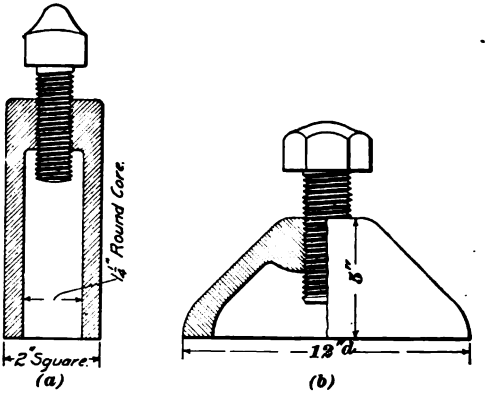


FIG. 9.

into a cast-iron base *b*, the bottom of which is faced. A cap *c* is attached to the screw by means of a ball-and-socket

joint. This jack serves the same purpose as the one shown in Fig. 7 (*a*), and, like that jack, is useful for work having the surface that is to be supported at a slight inclination to the supporting surface.

20. Sectional Jack. — A jack-screw that embodies some good features is shown in Fig. 8. The body is made up in sections, as shown, and has a base *a* that can be used with one or all of the sections. A removable cap *b*, which is hollowed out on the lower side so as to fit the rounded head of the screw and which has a V groove cut into the upper side, is a great convenience for some classes of work. This jack, as found on the market, may, with its various bases, be adjusted in height from about $1\frac{1}{2}$ to 6 inches.

21. Laying-Out Jack.—A jack that has been found very serviceable in laying out is shown in Fig. 9 (*a*). A screw with a square head, which is rounded at the top, is screwed into a square cast-iron body. The body may be cored out as shown, in order to lighten the jack.

22. Simple Erecting Jacks.—Fig. 9 (*b*) illustrates a simple and serviceable erecting jack that can be made at

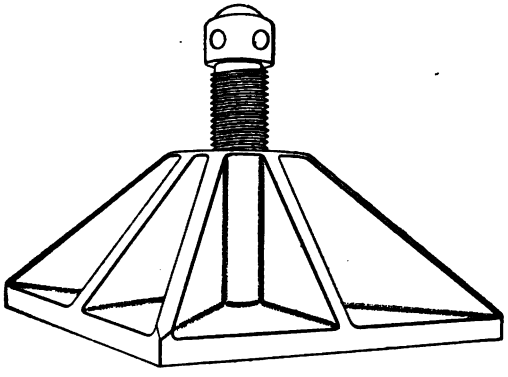


FIG. 10.

very small cost. These jacks are low, yet have enough adjustment for a great deal of ordinary erecting work. Another jack of the same class, and used for the same kind of

work, is shown in Fig. 10. It is made strong and rigid in order to serve for heavy work, and has a large base, which is a very great advantage either upon earth floors or where the floor is not perfectly rigid.

23. A great deal of time may be saved by using jacks, as they can be adjusted more quickly and more accurately than the same adjustment could be made with blocks and wedges. Any number of jacks permitted and required by circumstances may be used at different points of a heavy part in order to support it properly.

24. Heavy Erecting Jack. — The jack shown in Fig. 11 may be used for work that is excessively heavy and where there is much vibration. The screw is made with a square thread and has a cap *a* mounted on a spherical head. The screw is turned by means of a round bar inserted in the holes in the enlarged part *b*. The foot *c* of the jack is made heavy and stiff. The upper part of the foot, that is, the threaded portion, is slotted as shown at *d*, so that when the screw has been adjusted to the proper height it may be clamped by means of the bolt *e*, thus preventing any rotation of the screw while the work is being done.

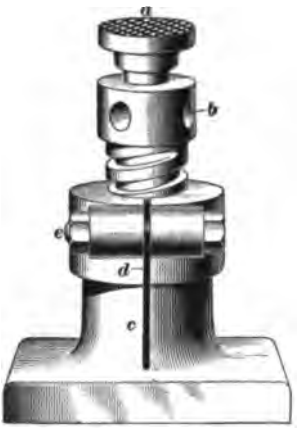


FIG. 11.

25. Lifting Jacks.—When jacks are required for the purpose of lifting, a different design with a greater screw travel becomes necessary. Fig. 12 is an illustration of a jack of this class. The head of the screw is made with a cast-iron cap *a* that rests on a solid collar *b*; the upper end of the screw is turned down to pass through the cap and is beaded over to prevent the cap from coming off. A round bar inserted in the holes at *b* is used to turn the screw.

It will be seen that this jack cannot be used with a straight handle in places where the screw cannot be turned through an angle of at least 90° at each setting of the bar. By bending one end of the bar through an angle of 22½°, and inserting the bent and straight ends alternately, the angle through which the screw turns for each insertion of the bar is greatly reduced. It is thus made possible to operate the jack in a comparatively narrow space, but the amount of time required for the constant resetting of the bar is so great that this method becomes objectionable where much work of this kind is to be done. A jack fitted with a reversible ratchet for operating the screw is preferable in most cases, since a great deal of time and hard work is saved by its use, as the handle of the ratchet can be turned back more easily and in much less time than a bar can be taken out, turned end for end, and again inserted. With a properly formed ratchet, the jack can be operated in a very much smaller space than one operated by a detachable bar.



FIG. 12.



FIG. 13.

26. Track and Stone Jacks.— When erecting work in a shop where the facilities for handling are not good, and also for handling it upon the final site, **track jacks** and **stone jacks** are very often used, on account of their great convenience. Fig. 13 illustrates a stone jack regularly made to lift 12 tons through a height of about 20 inches. The load is carried either on the head *a* or on the toe *b*. The work is raised by turning the handle *c* about its center, thus turning a train of reducing gears that engage with the

rack *d*. The track jack embodies the same principles as the stone jack, but is operated by a lever instead of a gear-train.

27. Hydraulic Jacks.—Hydraulic jacks of different kinds are used very largely in well-equipped machine shops. A hydraulic jack has a plunger that operates in a cylinder into which water, alcohol, or oil is pumped. When hydraulic jacks are subjected to cold temperatures, alcohol must be used, on account of its resistance to freezing. The lifting is done by the pressure of the fluid in the cylinder. A small hand force pump is contained in the body of the jacks, by

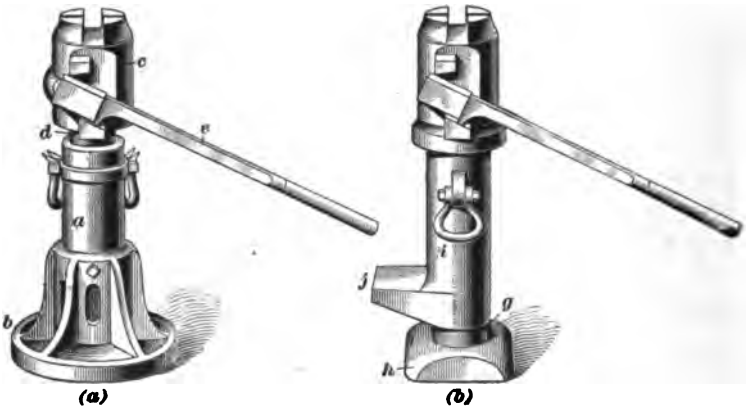


FIG. 14.

which the necessary pressure is obtained. Fig. 14 (*a*) shows a hydraulic jack in which the cylinder *a* is a part of the foot *b*, while the head *c* is attached to the plunger *d*. The pump mechanism, which is enclosed in the head, is operated by the handle *e*.

28. Fig. 14 (*b*) illustrates a hydraulic jack in which the plunger *g* is attached to the foot *h*, and the cylinder *i* is attached to the head. The pump mechanism is practically the same as in Fig. 14 (*a*). The arrangement shown in Fig. 14 (*b*) permits a lifting toe *j* to be cast on the lower end of the cylinder, thus making it possible to secure a low

hold, which is not possible with the arrangement shown in Fig. 14 (*a*).

29. Hydraulic jacks range in capacity from 3 to 150 tons; the larger sizes are sometimes used as hydraulic presses by attaching them to the work by means of suitable bars. In such a case, a convenient portable press is obtained that is suitable for work that cannot be taken to a stationary press.

MACHINE FOUNDATIONS.

30. Introduction. — The erecting of a machine is usually understood as including both the erecting in the shop in which it is made and the erecting upon the final foundation. The two differ principally in the amount of fitting and adjusting that is to be done and the facilities for handling the heavier parts. The fitting and the adjusting of all the parts are done in the shop, except in cases where some of the parts are dependent on the foundation, or must be fitted to other parts that are not available in the shop.

31. The machine should in all cases be made as complete and as perfect as possible before it leaves the shop, since the entire equipment of the shop is available, and the work can be done to better advantage. Any fitting that is necessary while setting up the machine upon its final foundation must be done with a few light tools that can easily be shipped, and with such makeshift devices as the workman may be able to make. His ingenuity is often severely tested, and the most skilful workman frequently finds it impossible to produce the grade of work that could easily, and at a much smaller cost, be produced in the shop. It is therefore a matter of economy to be sure that every part is properly fitted and the entire machine as complete as possible before it is shipped. The erecting on the final foundation should consist simply of putting the parts together and making the final adjustments. This is, at best, not an easy task, especially when the machine is heavy, as the facilities

for handling are almost invariably temporary makeshift devices that operate slowly.

32. Permanent Foundation and Foundation-Bolt Templet.—The permanent foundation is usually built up of concrete, brick, or stone. In building the foundation, due provision must be made for the foundation bolts. Sometimes these bolts are built solidly in the foundation, while at other times they are set in pipes that hold the concrete or cement while it hardens yet permit the bolts to be adjusted or removed entirely, if that should be necessary. In either case the bolts must be carefully set, so that when the bed of the machine is lowered in place they will meet the bolt holes. It is usually best to make a wooden templet having the exact thickness of the bed parts, with holes in the exact location of the bolt holes in the bed through which the bolts pass. It will be seen that by locating such a templet carefully where the machine is to stand, the bolts can be set to the proper height and in the right place; the foundation may then be built up without any danger of a misfit.

ERECTING FLOORS.

33. Introduction.—The erecting in the shop is done on a floor, the construction of which depends on the weight of the machines and the condition of the earth on which it is built. When the earth is dry and hard, or there is a rock bottom to build upon, the foundation of the floor may be shallow; on the other hand, when the earth is wet or unstable, a deep and solid foundation should be built up. The depth of the floor foundation depends on the weights of the heaviest parts that are liable to come upon it.

34. Erecting floors are made up in different ways, depending on the class of work to be done; that is, whether they are intended for permanent use for one class of work, or for a wide range of work, the needs of which cannot well be anticipated and for which changes must constantly be

made. The first cost, also, in many cases, becomes an important factor, and determines the style of floor used. To meet the various requirements, the following kinds of floor are made: *earth*, *wooden plank*, *scantling*, *wooden block*, *brick*, *concrete*, and *iron plate*.

35. Earth Floors.—In places where the earth is of a firm and solid character and little money can be spent for a floor, the earth is simply leveled and packed down so as to make a smooth, hard floor. Sometimes the surface is formed of a layer of iron chips from 1 to 4 inches thick that are mixed with salt or other material that will cause them to rust. When they are well packed, the surface will rust into a solid smooth mass and then form a very good floor. Besides being cheap, the earth floor can easily be dug up to form a pit to enable any machine parts that project below the floor line to be attached. On the other hand, there is always more or less loose sand upon the surface, which is liable to get into the working parts of a machine and thus cause trouble.

36. Single-Plank Floor.—A comparatively inexpensive floor consists of 3- or 4-inch yellow-pine planking, laid across joists that are placed close together and are well braced or bridged sidewise. The planks are sometimes covered with a diagonal floor of $\frac{3}{4}$-inch to $1\frac{1}{4}$-inch pine. The spaces between the timber should be ventilated. This style of floor is, however, not very rigid, and, hence, the heaviest grades of work require something more solid.

37. Double-Plank Floor.—A more rigid floor than the plank floor previously mentioned is illustrated in Fig. 15. The floor is built up of $2'' \times 4''$ pine scantling a, a, with a facing of from $\frac{3}{4}$-inch to $1\frac{1}{4}$-inch pine boards laid diagonally, as shown. The scantlings are laid upon timbers c, c, which are laid in a concrete bed. The thickness of the concrete depends largely on the condition of the ground, but if it is of a firm grade, 14 inches should be sufficient for all ordinary purposes. The bed is built up by first laying a course of coarse stone, as shown at d, and running in some cement,

then following with successive finer grades of broken stone, and finishing with a very fine grade. Air spaces *e*, *e* are left between the timbers; these may be ventilated by means of openings through the walls or by holes bored through the

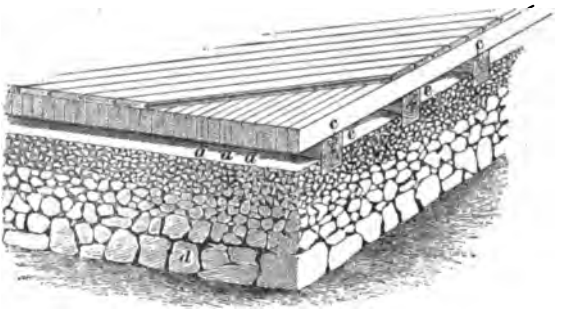


FIG. 15.

floors. Many persons claim that this precaution should be taken with all wood floors to prevent rotting. The timbers *c*, *c* are made 4 in. × 4 in., 4 in. × 6 in., or 6 in. × 6 in., depending on the duty for which it is intended. When the 4″ × 6″ timber is used, it is laid on its flat side. The distance between the timbers should not be much greater than the thickness of the concrete, and it is generally thought best to limit the distance to the thickness. This makes an excellent floor, and, by some, is preferred to all other styles.

38. A very good floor is made with a base of tar concrete. The ground, after leveling, is covered to a depth of about 6 inches with a layer of sand that is well rolled down. On top of this, 6 inches of tar concrete is placed; the concrete is composed of small broken stones covered thickly with heated tar, and, after leveling, is rolled with a heavy roller. Finally, a layer of sand mixed with considerable tar and some asphalt is applied, while hot, to a depth of about 1½ inches and after it is rolled down, is allowed to harden. When hard, a layer of 3-inch spruce planking is placed on top of the asphalt, and 1⅛-inch dressed maple flooring in strips about 4 inches wide is finally nailed crosswise to the spruce planking. The maple flooring is not tongued and

grooved. It will be observed that no air space is left between the concrete and the flooring in this design, and that the planking is laid directly upon the concrete. One prominent firm states that they have not experienced any trouble by the rotting of the planking, as is claimed by many to occur when the flooring is laid directly on the concrete. The quality of the timber used and the amount of dampness in the location are important factors to be considered when deciding upon the kind of floor to use. A tar concrete floor is rather expensive, but very solid.

39. Wooden-Block Floor.—A substantial floor may be made of sawed wooden blocks, either cedar, pine, or oak, that are placed on top of a concrete bed. One prominent firm has constructed a wooden-block floor in the following manner: After leveling the ground, a layer of cinders 6 inches thick was placed on the ground and thoroughly rolled down with a heavy steam roller. A bed of concrete 4 inches thick was laid on top of the cinders and thoroughly leveled. The blocks were 6 in. × 4 in. × 4 in., sawed from well-seasoned oak; their ends were dipped into liquid asphalt, and the blocks were then laid directly on top of the concrete bed.

Another firm omits the cinders and places the concrete bed directly on the leveled ground, making the concrete bed about 8 inches thick. The blocks are cedar wood sawed to 3 in. × 12 in. × 5 in.; these are placed end to end and butting together on the concrete, so that their height is 5 inches. A space of $\frac{1}{4}$ inch is left between adjacent rows, which is filled with a mortar composed of 1 part of Portland cement to $2\frac{1}{2}$ parts of sand.

The advantages of a wooden-block floor are as follows: (1) It is easy on the feet of the workmen. (2) The work is not so liable to slip on it as on other kinds of floors. (3) Cleats, braces, etc. can be readily attached to the floor. (4) The expense of repairing it is slight.

40. Brick Floors and Concrete Floors.—Occasionally, a floor is made of brick laid in cement and placed on

a solid concrete foundation. Sometimes hard paving bricks that are laid on edge are used instead of ordinary bricks, and cement is run in between them to fill the cracks. In some localities, a concrete base is covered with a thick layer of cement, which forms a very smooth and hard floor that is impervious to moisture.

41. Cast-Iron Plate Floors. — The cast-iron plate floor is perhaps the best floor for large work, but its great expense has in the past prevented its coming into general use. It is, however, adapted to so many uses that, in many shops, the expense is warranted, since it serves as a laying-out table, a machine-tool foundation, and a machine-tool table, and, also, as an erecting floor. In large shops, especially where there is a large amount of work that is too heavy to be machined in the stationary machine tools, such a floor provides an excellent means for setting up the heavy parts and doing the machining with portable machine tools, such as radial drills, traverse head-shapers, slotting machines, special milling and grinding fixtures, etc., which may be driven by means of ropes, electric motors, or compressed air.

42. One or two large horizontal boring mills may be set alongside an iron-plate floor in such a manner that the floor forms the table of the machines; this arrangement has been found very convenient in shops where much boring is done on large pieces. A planer set with the side of its bed against such a floor may also be made to operate on a heavy part fastened upon the floor, by means of a special head bolted to the table.

43. The top of the floor should be planed true, and should be provided with T slots for the purpose of allowing the work or portable machines to be bolted to it. The slots are usually made at right angles to each other, although sometimes they are all made parallel to one side; occasionally, when much circular work is to be machined upon the floors, the slots are run in concentric circles with radial slots crossing them at regular intervals.

44. The plates are generally made stiff enough to allow them to be supported upon masonry columns without deflection. This greatly facilitates the leveling up of the plates, when, for any reason, they get out of true. Sometimes they are laid in a solid bed of concrete. The plates are then supported at every point, and when the foundation is heavy, and the plates are leveled up very carefully when they are first set, the floor is quite satisfactory for some time; but if, for any reason, the foundation should yield slightly, or the plates should not be set quite right at first, it is impossible to set them true without taking up the whole floor and resetting it completely. This is a very expensive piece of work, and, for this reason, the masonry supports with openings between them that make all parts below the floor accessible are generally preferred. Iron plates are sometimes objected to because they are cold and slippery, but after workmen have become accustomed to an iron floor, these objections are soon forgotten.

FLOOR PITS.

45. Introduction.—It is often necessary in erecting large work to make provision for parts that extend below the floor line, or to get at some of the parts from beneath the machine. For this purpose, pits are made at suitable places in the floor. These pits are often made with cast-iron floors about their edges, and are often lined with plates with T slots running down at intervals on the inside. Pits are also used in machining very large pieces, such as flywheels, that are too large to be machined on a boring mill or in a lathe.

46. The construction of pits, like the construction of erecting floors, depends very largely on the class of work done in the shop. When a definite line of manufacture is carried on, a pit suited to the needs of the work can be built, but where work of a miscellaneous character is done, it is

impossible to anticipate the needs that may arise at any time, and a pit that can easily be enlarged or changed will be the most suitable.

47. Pit Construction for a Definite Line of Work.—Fig. 16 shows a pit that is built for the purpose of erecting vertical boring mills. The sides of the pit *a* are built up of brick or stone, and iron plates *b*, *b* are placed all

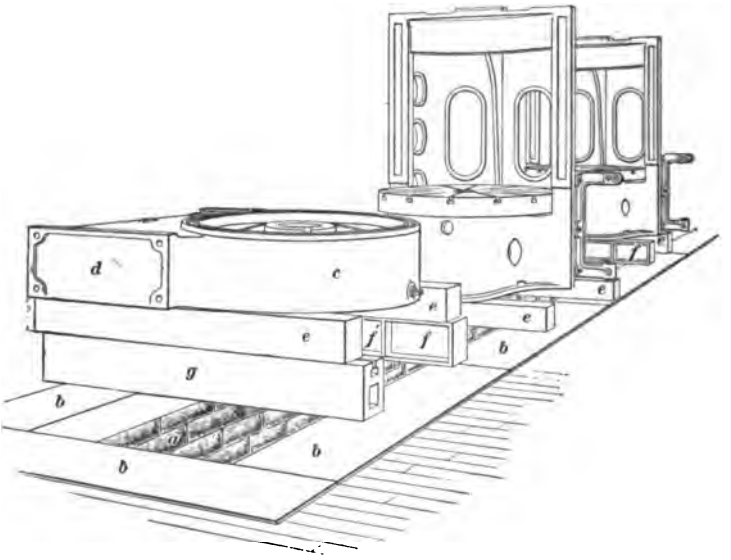


FIG. 16.

around the mouth of it, as shown. A convenient size of pit for this class of work is made about 4 feet deep by 4 feet wide; the length depends on the amount of work to be done.

48. The bed of the machine that is being erected is usually mounted upon parallels placed across the pit, as shown in the illustration. It will be observed that two styles of machines are shown in Fig. 16. The machine *c* has the housings attached to the sides of the bed at *d*, and the table is rotated on a spindle that extends below the bottom of the bed. The lower end of the spindle is carried in a step bearing that is placed in a frame which is bolted to the

bottom of the bed. In order to fit this frame properly, it is necessary to have plenty of room beneath the bed; for this reason, the bed is placed upon two parallels on each side. The other two machines shown are self-contained. The housings and the bed are one casting, and the spindle of the table does not extend below the bed. In this case, one set of parallels is sufficient to support the machine during erection.

49. Fig. 16 incidentally illustrates several styles of large parallel bars. The bars *e*, *e*, which are made of cast iron, have the general form of a box that is open at the bottom and is subdivided into several compartments by webs. These webs tie the tops and sides together and greatly stiffen the bar. The object of making the bars hollow is to reduce their weight. It is an advantage to have all the bars in a set made the same height, since three or more can then be used for supporting a large piece of work having a plane surface at the bottom.

The parallel bars *f*, *f* have an **I** section and are strengthened at regular intervals by ribs, as, for instance, by the one shown at *f'*. A large parallel bar, as the bar *g*, for instance, is occasionally made with a rectangular hole and a **T** slot cored in it. The **T** slot permits work to be attached to the bar by means of bolts and clamps.

50. Large Masonry Pit.—Fig. 17 shows a large masonry pit intended for large and heavy work. For a given class of work, such a pit should, when possible, be designed so that it will be suitable, especially to that class of work. For general work, a pit must be designed to cover as broad a range of work as possible. A pit about 40 feet long, 12 feet wide, and 20 feet deep is a size well adapted for heavy work. The one shown in Fig. 17 suggests a design that is suitable for most cases. The ends *a*, *a* and the sides *b* may be built up of stone, while the bottom *c* is made of concrete and faced with cement. The top of the pit is surrounded with cast-iron plates *d*, *d*, provided with **T** slots, the plates being planed and set level. The ends of the pit may be

built up in steps, as shown, or may be made straight, as indicated by the dotted lines *e*, *e*.

51. When the pit is not in use, it is covered with a plank floor, a section of which is shown in place at *f*. The floor is supported upon **I** beams, as *g*, which are set in pockets *h*, *h*, in the sides of the pit. The covering floor is

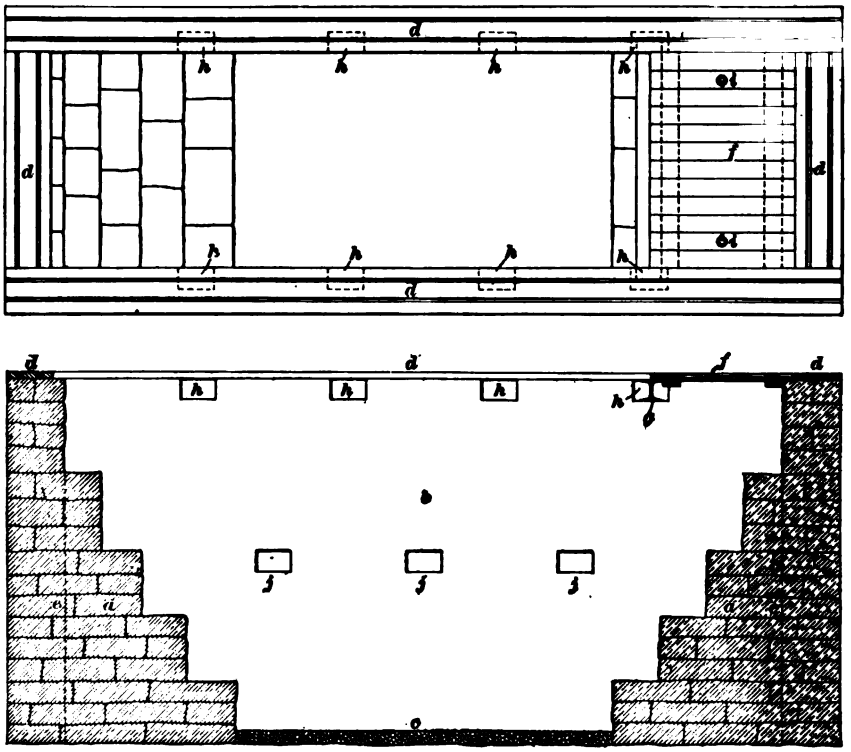


FIG. 17.

made up in sections so that it can easily be removed, and each section is provided with two rings *i*, *i* to facilitate the handling. The rings are attached with staples and let into the plank, so that when they are not in use they lie below the surface of the floor. These pits may be made with one

or more sets of pockets *j*, *j* to receive the **I** beams, upon which to support sections of the floor when the full depth of the pit is not required. Such a pit may be used either for erecting or for machining large parts, as described later.

In some shops it is preferred not to floor the pit over. In such a case it is advisable to place a stout removable hand railing around the pit to prevent workmen from stumbling into it.

52. Another style of pit, which has the advantage of being both cheap and easily changed or enlarged, is shown in Fig. 18. The earth is simply dug away where the pit is to go, and the floor, which rests upon heavy horizontal tim-

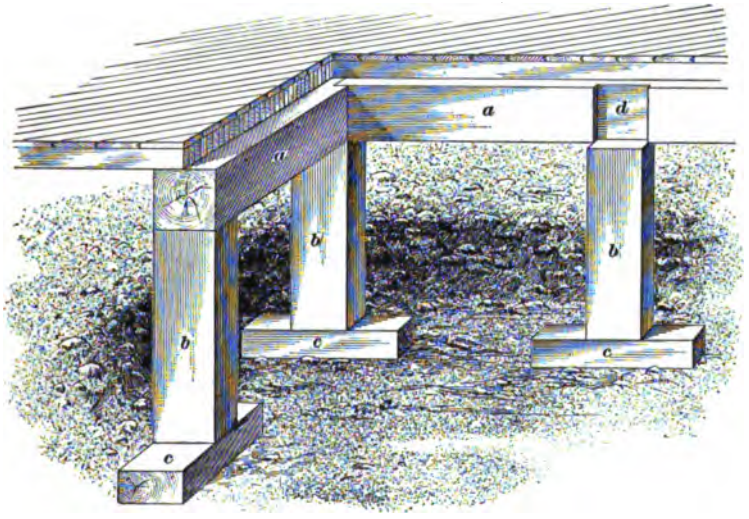


FIG. 18.

bers *a*, *a* is supported about the outside of the pit by means of vertical timbers *b*, *b* standing upon blocks *c*, *c*. The floor, which covers the pit when it is not in use, is made in sections and is supported by timbers that are set into pockets *d*, which are cut into the side timbers.

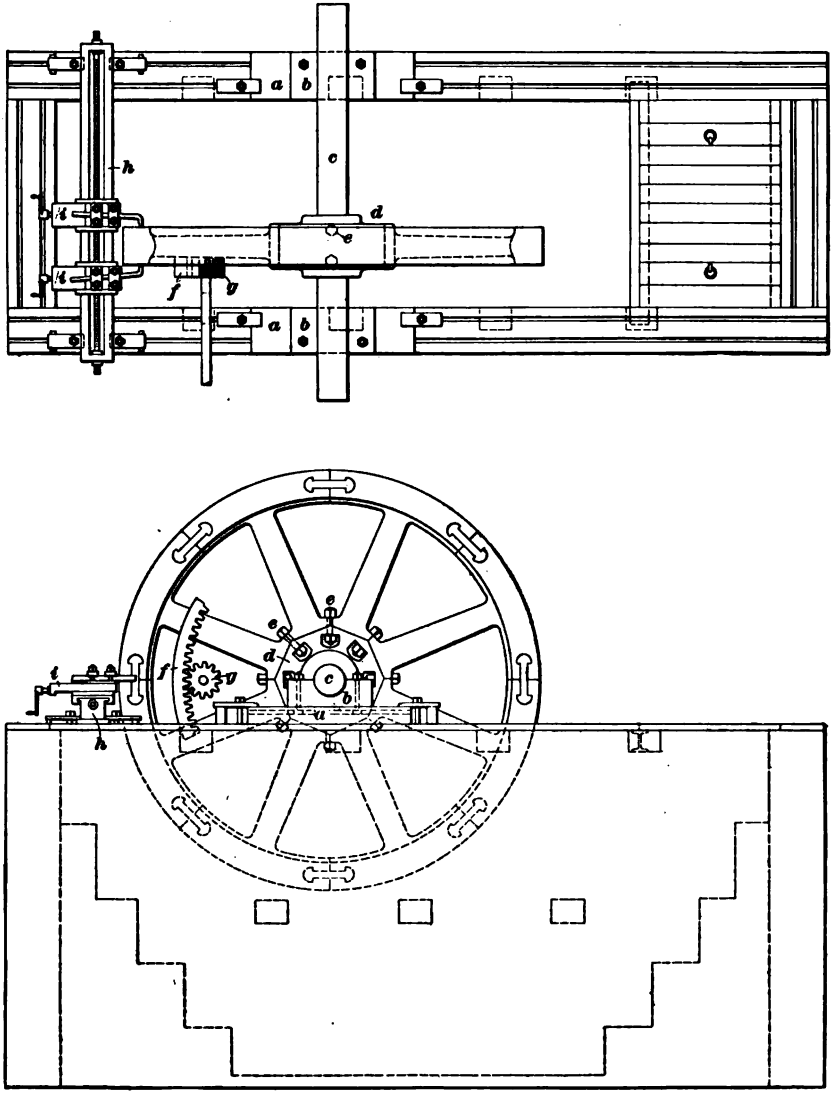


FIG. 19.

USE OF ERECTING PIT.

53. Assembling a Flywheel.—Large flywheels, rope wheels, gear-wheels, and other similar wheels are usually assembled in the erecting pit. The assembling and machining of the rim of a large built-up flywheel is an excellent example of the use of the erecting pit. One method of doing this work is here described. Parallel bars *a*, *a*, Fig. 19, are bolted opposite each other to the plates surrounding the mouth of the pit, and temporary bearings *b*, *b* that will bring the center of the shaft *c* about 30 inches above the floor level, are placed on top of the parallel bars so that they are fairly in line with each other. The shaft *c* with the hub *d* on it is now picked up by a crane and lowered into the bearings, which are properly alined to suit the shaft. The bearings, which do not need any caps, are now bolted down to the parallel bars. In another method of lining the bearings, the shaft is blocked up until it is level; the bearings, which are considerably larger than the journals, are shifted into place and bolted down, and Babbitt metal is poured into the bearings around the journals.

54. All the joint faces of the sections of the rim having been properly faced prior to the erection, one section is picked up by the crane and gently lowered on the hub, to which it is fastened while in a vertical position by temporary bolts. The shaft is now revolved sufficiently to bring the next seat of the hub to a horizontal position, and after the fastened section has been securely blocked to prevent rotation of the shaft, another section is lifted into place and is attached to the hub and the first section. This operation is repeated until the wheel has been assembled. The holes in the arms and hub are now reamed one by one to match exactly, and the permanent bolts are then carefully fitted, driven home, and the nuts securely screwed up, as shown at *e*, *e*.

55. In order to turn the sides and face of the rim, means must be provided for revolving the flywheel. A common

method is to bolt a large annular gear, which, for convenience, is made in short sections, to the arms of the flywheel. One of these sections is shown at *f*. A pinion *g* is then placed in mesh with the gear and is driven either by a rope drive, by a belt from an overhead shaft, by an electric motor, by a small steam engine, or by a compressed-air engine, as is most convenient. A heavy bed *h* is then bolted across the pit; it may carry two slide rests *i*, *i*, in order to allow both sides of the rim to be finished at once.

56. If the flywheel is to have the rim polished, a grinding rig carrying a suitable emery wheel may be mounted on the carriage *i*. The emery wheel, which is driven in any convenient manner, is then fed slowly across the surface that is to be ground while the wheel is revolving at a suitable speed.

57. Cutting a Large Spur Gear.—Spur gears 50 feet or more in diameter may be cut in the following manner: They are built up with as much in the pit as will bring the center of the shaft within as convenient a working distance of the floor as possible. The spaces between the teeth are generally cast in with enough allowance to insure cleaning up.

58. A rest or bed similar to that used for turning, but carrying a back-geared milling head that may be traversed the whole length of the bed is placed across the pit, parallel with the shaft that carries the wheel. The bed is blocked up until the axis of the milling spindle and the axis of the wheel shaft are at the same height above the floor. The wheel is generally erected with the top of the teeth left rough; these may be finished by means of a milling cutter fed across the face of each tooth in succession, thus bringing the gear blank to the correct outside diameter. The pitch circle is next laid out on one side of the rim, and is divided as accurately as possible by means of a pair of dividers. In order to insure accurate spacing of the teeth, it is well to go around the pitch circle with a pair of trams, using as long a cord as possible, and then subdivide the large divisions with dividers The thickness of the teeth on the pitch circle is

then laid off and all points of division are carefully marked with fine prick-punch marks. The spacing for the teeth is then obtained by making the division marks representing the circular pitch successively coincide with the end of a stationary pointer. Suitable clamps will have to be provided for holding the wheel still while the cuts are taken.

59. A pair of end mills may be used for cutting the tooth spaces, of which the roughing cutter is about $\frac{1}{16}$ inch smaller in diameter than the finishing cutter. The section of the finishing cutter must be exactly a duplicate of the profile of the space between the teeth. The roughing cutter may have nicked teeth, but the finishing cutter should be left plain. Both cutters can advantageously be given spiral cutting edges.

60. The cutting of large gears in the manner just explained may be expedited by using two cutting heads for roughing out the spaces and facing the end of the teeth, placing a cutting head at each side of the wheel. The finishing should be done by one head entirely.

61. Assembling a Large Rope Wheel.—Large rope wheels are usually built up, the rim, hubs, and arms being separate pieces. The rim itself in many cases is made in segments. The following description shows the method that is in vogue in one prominent shop for assembling such a wheel, the wheel whose assembling is here described being 25 feet in diameter and having a face 7 feet wide, which contains 36 turned grooves for $1\frac{3}{4}$-inch rope. The wheel has two hubs with 10 arms for each hub; the rim is built up out of 10 segments that are securely bolted to one another. The arms are bolted to the hubs and to the rim.

62. The hubs having been forced on the shaft, the latter is placed in temporary bearings placed at opposite sides of the erecting pit. The arms, the bolt holes in the ends of which have been previously drilled and reamed, are now placed in position, two opposite arms on each hub at a time, and are supported on timbers placed across the pit. They are

then attached to the hubs by temporary bolts, and the holes in the hub are reamed in line with those in the arms. The permanent bolts are now fitted, driven home, and secured by nuts. All the arms having been fastened, the sections of the rim are attached one by one until the wheel is completely assembled.

63. For turning the grooves for the ropes, the wheel is driven by one of the methods explained in Art. **55.** A bed that carries one or more slide rests having been bolted across the pit, the face of the wheel is turned to the right diameter and the position of the grooves is then laid out. Square-nosed tools are used to rough out the grooves, a wide one being employed for the wide part of the groove and narrow ones for the narrower parts. The bottom of the groove is generally made round; hence, the finishing tool for this part is made with a round nose having the radius called for by the drawing. Right-hand and left-hand side tools are used to remove the remaining stock and to bring the sides of the grooves to the correct form for finishing. The right-hand side tool is used in one slide rest and the left-hand tool in the other slide rest in order to prevent undue thrust in one direction, as would result if two tools cutting in the same direction were used at once. The finishing is done with a formed spring, or gooseneck tool, in order to have the finished work free from chatter marks. The sides of the rim are turned square with the face, and any special turning that may be specified on the drawing is done.

64. The wheel should be rigidly inspected as the turning progresses, and if cracked or defective castings are found in the rim, they should be replaced before the wheel is taken down for shipment. A defective or broken segment may have a new one fitted in its place, and the new segment may be turned without great loss of time by using a reversing countershaft and running the one segment back and forth past the tools until it is roughed out like the rest and then taking a light finishing cut over the whole wheel. This method effects a great saving on a large wheel that

may make only 1 revolution in 5 or 6 minutes. The work having been completed, the different parts are plainly marked to show which way they go together, and the wheel is then taken apart for shipment.

65. Using Erecting Pit for High Work.—Vertical steam engines and other machines that are too high to be erected on the erecting floor may often be erected on the bottom of the erecting pit, thus gaining the extra head-room afforded by the depth of the pit.

DRIVING FITS, PRESS FITS, AND SHRINK FITS.

66. Introduction.—Two pieces of work may be joined together by creating sufficient friction between them to prevent separation except by undue means. This is done in practice by making one part slightly larger than the other part, and placing the larger part into the smaller one, or placing the smaller part over the larger one.

67. The parts that are to be joined may be placed together either by pressing or driving one of them into or over the other, or one part may be expanded by heating and it may then be dropped over the other and left to cool. Fits that are made by driving the pieces together are called **driving fits,** while those in which the pieces are pressed together are called **press fits.**

68. When one piece is expanded by heating and is then dropped over the other, it tends to return to its original size in cooling, and if the proper allowance has been made it produces a very rigid and durable joint. This is called a **shrink fit.** Shrink fits are frequently applied in making the joints of flywheels, strengthening short pipe bends, etc. In all these cases a link or bolt, which is made a little shorter than the place in which it is to go, is heated until it goes freely into place, and then allowed to cool, thus drawing the parts tightly together.

69. Either the driving fits, pressed fits, or shrink fits, when properly made, produce excellent joints, but when a

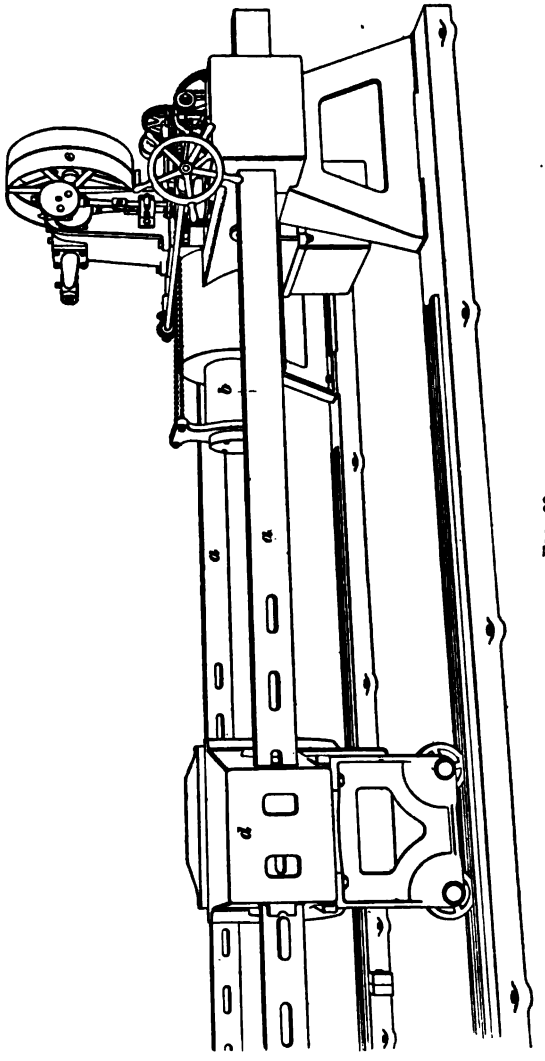


FIG. 20.

shop is properly fitted up with presses, and the character of the work permits it, the pressed fit is preferred by many.

When no press is available, the parts may be driven together with hammers or rams. There are, however, cases where neither a press nor a ram can be applied, and the shrink fit may be used to the best advantage.

70. General Construction of Hydraulic Press.—Fig. 20 shows one style of a hydraulic press that is made of 200-, 300-, and 400-ton capacity, and is used for such work as pressing the cranks on engine crank-shafts and general pressing on or off in making press fits. The tie-bars *a*, *a* are placed on either side, so that the work can be lowered into, and lifted out of, the press with a crane. For use in railway shops, the tie-bars are placed one below the floor and the other overhead, thus enabling the rolling in and out of the car wheels or locomotive wheels. The same tie-rods, or similar ones, may be used with hydraulic jacks for portable-press work.

71. This particular machine will take 10 feet between the tie-bars and 25 feet between the ram and sliding head. The ram *b* is 14 inches in diameter, has a stroke of 4 feet, and is provided with a counterweight so that it returns automatically when the release valve is opened. It is provided with a safety valve that can be set to open at a desired pressure and is then locked up in a box cast on the cylinder, which makes it impossible to push more than a specified amount. The pressure gauge is graduated for tons pressure on the ram and pounds per square inch of its area. The sliding head *d* moves on a track, and is held in position by steel keys. The force pump is driven by a belt placed on the pulley *e*, and takes its water supply from a tank underneath, to which the water is returned.

72. Portable Press.—For work that is too large to be placed in such a machine, a portable form may be used that can be taken to the work and can be made to conform to its varying conditions. If the portable press is near the stationary press, it may be operated by connecting it to the power-driven pump of the latter; it may also be connected to the hydraulic service pipe in shops provided with a

hydraulic service. If the necessary hydraulic pressure cannot be obtained in either one of these ways, the press may be operated by a hand force pump.

73. All shops have more or less work that requires to be driven or pressed together; for instance, large mandrels which must be put in and taken out. These operations, which often require the help of several men, may be easily and quickly done by the aid of a small portable press like

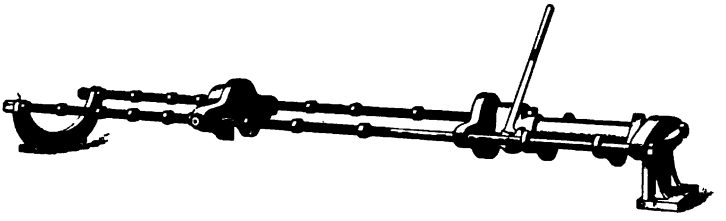


FIG. 21.

that illustrated in Fig. 21. This press, as can be seen by referring to the illustration, has two bars $1\frac{1}{2}$ or 2 inches in diameter that are threaded for two-thirds of their length on one end and enough on the other to take a nut. Nuts are screwed on at intervals to form stops for the movable head, and two supports are provided for a hydraulic jack. This tool may be made to suit the needs of the shop in which it is to be used, and any ordinary shop jack, not exceeding in power the strength of the side rods, may be used with this device.

74. Press Fits.—Press fits may be classed under two heads: *taper fits* and *straight fits*. If a standard 1-inch cylindrical plug-and-ring gauge be tried together when they are at equal temperatures, it will be found that the plug can only be pushed through the ring by exerting considerable force. The reason for this is that the size of each gauge is so near that of the other as to make the fit almost perfect. If a person will hold the ring in his hand for 5 minutes, the ring will become larger, and he will find that he can push the plug through it easily; and if he will dip the plug into

cold water and warm the ring, the difference in size becomes so great that the plug will fall through. From this experiment it is seen that the pressure required to press two parts together depends on the difference in their size.

In a press fit, the internal piece, as a shaft, for instance, must be enough larger than the hole to insure the development of enough friction between the two pieces to hold it there securely when pressed home. The amount of friction is judged by the total pressure in tons on the piston of the hydraulic press that is required to press the pieces together. The allowance that has to be made, i. e., the difference in the diameter of the two pieces that is required in order to insure a pressing together at a given pressure, cannot be calculated with any degree of accuracy, as the pressure depends on a number of variable factors whose values cannot be determined, even approximately. Some of these factors are the length of the hole compared with its diameter, the relative smoothness and truth of the two surfaces that are to be joined, the amount of metal and the manner of its distribution around the hole of the external piece, and the character of the material. For this reason, experience, judgment, and experiment must be relied on; in order to aid the judgment, several cases taken from actual practice are here given.

75. In one instance, a car-wheel seat $4\frac{7}{8}$ inches in diameter and 7 inches long required 30 tons to force it over the axle, an allowance of .007 inch having been made. In another case, two crankpins were required to go in holes 5 in. × 8 in. at 50 tons pressure. A gauge was made to the diameter of the holes, and another one was made .003 inch larger. The pins were turned to the size of the larger gauge, and went home at a pressure of 45 and 48 tons. It is the practice of one company to bore the hole of car wheels $4\frac{1}{8}$ inches in diameter, making the hole cylindrical, and to turn the axle a little tapered, just enough to be discernible to the calipers, probably .003 to .005 inch; the holes being 5 inches long, the wheels go home under a pressure of

30 tons. It is clear that where such a great pressure is required to force the pieces together, there must be considerable wear on the surface of both parts as they are being pressed together; hence, it is customary, instead of turning the internal piece cylindrical, to turn it with a taper of $\frac{1}{1000}$ of an inch to the inch of length of the hole to be fitted. If the hole is very long, less allowance may be made.

76. Taper Press Fits.—For many purposes, the taper fit is preferable to the straight fit. In a taper fit, the hole is bored tapered, generally $\frac{1}{16}$ inch per foot, and the internal piece is turned to the same taper as the hole, or in the practice of some, an increase of $\frac{1}{1000}$ of an inch to the inch of length is allowed; that is, if the large end of a hole 20 inches long measures 15 inches, the large end of the internal piece would be made 15.020 inches in diameter. If the hole is very long, the amount allowed may be made less.

77. Taper-pressed fits are sometimes made in the following manner: The hole in a hub, wheel, or crank is first bored with a taper of, say, $\frac{1}{16}$ inch per foot. A hollow cast-iron plug is then turned or ground to correspond to the hole and used as a sort of cylindrical surface plate to which the inside of the hole is scraped until it is true and round. The pin or shaft is then accurately fitted to go in to within a certain distance of its final location, generally to within from 1 to 4 inches. The following illustration, taken from actual practice, serves to illustrate the manner of fitting up this class of work.

An engine shaft 22 inches in diameter carried a hub for its flywheel that had a bore 30 inches long. The hole in the hub was scraped so that the hub would slide to within $4\frac{1}{4}$ inches of its location, and was pressed in the remaining distance. The hole in the crank was bored $18\frac{3}{4}$ inches and was 14 inches long; it was fitted to go within $3\frac{1}{2}$ inches of the shoulder of the shaft and was then pressed home. The crankpin had a bearing $9\frac{3}{4}$ inches in diameter by 11 inches long and was pressed $2\frac{1}{8}$ inches. In all these cases the shaft or pin had a taper of $\frac{1}{16}$ inch per foot.

78. Precautions.—Tables have been made by the formulas proposed for this class of work by various engineers, but they are of little value in general practice, since only experience will give results that are satisfactory. However, each shop can, to advantage, make useful tables from obtainable data and their own experience. It is better to allow a little too much in making a forced fit than too little, for if the internal piece is too tight, it may be pressed out again and may then be draw-filed to a smaller size.

Before putting the two parts together, they should be thoroughly lubricated with a heavy oil or grease, to prevent cutting, which might destroy the entire fit on both pieces. White lead is often used instead of oil.

79. Allowances for Different Fits.—The amount allowed on various kinds of work for fits, such as running fits, easy driving fits, tight driving fits, and force fits, are treated in a general way in the following articles and tables, which represent the practice of several good shops and may be taken as a general average of allowances made. Varying conditions, however, may call for different allowances, and hence the allowances here given must be modified to suit the requirements of the work. Running fits for work less than 1 inch in diameter may be made by making the internal piece .0015 to .002 inch under the size of the hole, while a $2\frac{1}{2}$-inch shaft may be as much as .003 under size. Driving fits are spoken of as tight and easy. A good tight driving fit is described as one-half, and a light driving fit as one-quarter, of the force fit.

80. The following table of diameters and allowances for force fits represents the average allowance made in several good shops; but, as has been said before, the conditions prevailing in the work being done govern the amount of force necessary to force two pieces together. For this reason the pressure necessary to push the parts together is seldom given with a table of allowances.

TABLE I.

FORCE-FIT ALLOWANCES.

Diameter. Inches.	Allowance. Inch.	Diameter. Inches.	Allowance. Inch.
½	.001	12	.012
1	.002	14	.014
1½	.003	16	.015
2	.004	18	.016
2½	.005	20	.018
3	.0055	22	.019
4	.007	24	.020
5	.008	26	.022
6	.009	28	.023
8	.010	30	.024
10	.011	32	.025

81. Shrink Fits.—In the absence of a press the shrinking process is often resorted to, but in general it is not as safe or satisfactory. In this process the internal piece is made larger than the hole it is to go into, and the external piece is then expanded by heat to allow the internal piece to be easily slipped in.

The amount to allow for a shrink fit is largely a matter of judgment, in which the material and the construction of the article must be taken into consideration. Krupp allows .01 inch to the foot of diameter in shrinking on locomotive tires, while American builders allow a little more, .012 inch in 1 foot being common practice. Care should be taken not to allow too much, since either the external piece will pull itself apart or the internal piece will be crushed or distorted.

The following table of sizes and allowances, adopted by the American Railway Master Mechanics' Association, gives the amount allowed in several American shops for shrinking tires on car wheels.

TABLE II.

SHRINK-FIT ALLOWANCE.

Diameter. Inches.	Allowance. Inches.	Diameter. Inches.	Allowance. Inches.
38	.040	56	.060
44	.047	62	.066
50	.053	66	.070

82. Examples of Shrinking.—It is often necessary to shrink a crankpin in, which may be done in the following manner. The pin is turned to the required size and the crank is then heated hot enough to allow the pin to enter freely. Care must be taken at this stage of the proceedings to guard against the pin sticking in the hole before it is clear in. A heavy sledge should be provided on both sides, as the pin may require a little driving to carry it clear home. If the crank should cool too rapidly, the pin must be backed out with the greatest possible promptness. When once in place, the pin should be kept as cool as possible by applying waste soaked in cold water, or by keeping a stream of cold water flowing on the pin. Care must be taken not to let the pin get as hot as the crank, or the pin may expand the hole and the fit will then not be as tight as was intended.

83. Shrinking a crank on a shaft is a job that is required to be done quickly. The shaft should be blocked up at a convenient distance from the floor, with the key seat up. The crank should be heated until the bore shows sufficient expansion to go on the shaft easily. If the crank is heavy, it should be picked up by a crane in such a position that the key seat will be on top, to conform to that in the shaft. All dust or dirt should be carefully brushed from the crank, which should be quickly shoved up to the shoulder on the shaft, and a temporary key, fitting sidewise, should

then be lightly driven in to keep the key seat in line. Means should be provided for holding the crank against the shoulder, or it may slip back and grip the shaft so tightly that it can never be brought up into its correct position. The permanent key may be fitted after the crank is cooled off.

84. A Special Heater.—A very convenient burner for heating parts in making shrink fits is shown in Fig. 22. A locomotive piston *a* is clamped between two wooden pieces, as shown in the illustration, and a gas burner *b*, which embodies the principle of the Bunsen burner, is supported centrally in the piston-rod hole. The burner has a number of holes on its circumference producing as many jets of flame, which strike the surface to be heated. An ordinary rubber gas tube *c* connects the burner with a gas pipe on the wall.

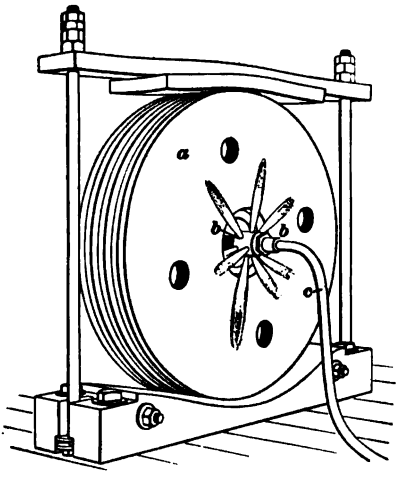


FIG. 22.

HOISTS AND CRANES.

HOISTS.

85. General Consideration.—It frequently occurs that the heavy parts of machinery, and often the whole machine itself, must be moved. This work, if it is done without proper appliances, requires the help of many persons, and in that case becomes very expensive with an increase of the size and weight of the parts to be moved. Light machine

parts may require no special appliances for hoisting, or at the most only an ordinary chain block.

86. Block and Tackle.—For some classes of work, and especially for erecting in the field, an ordinary block and tackle like the one shown in Fig. 23 is very useful. One advantage the block and tackle possesses is that it is generally possible to lift a weight to a greater height than with the chain block, since a longer rope can easily be reeved in and is more readily obtained than a chain.

Small blocks and tackles with $\frac{1}{2}$- or $\frac{5}{8}$-inch rope are often called **handy tackles.** The handy tackle is especially useful for drawing a weight suspended from a larger tackle to one side, or for moving machinery supported on rollers.



FIG 23.

87. Care should be taken to see that the tackle is always placed in its most advantageous position for hoisting or pulling. For hoisting with the tackle shown in Fig. 23, the hook *a* should be attached to some fixed support above and the hook *b* should be made fast to the work. In this case a given amount of pull on the rope *c* will cause an equal pull on the other ropes *d*, *e*, and *f*, so that, neglecting friction, a given pull on *c* can lift three times the load on the hook *b*. For dragging weights horizontally, the hook *b* should be attached to the stationary object and the hook *a* should be made fast to the moving load, the rope *c* being then pulled in the general direction of the tackle. This has the advantage of giving four ropes pulling on the block *g* and hence on the hook *a*.

88. Chain Blocks.—A great variety of chain blocks are used in the machine shop, of which the most common type,

known as the **differential chain block,** is illustrated in Fig. 24. A chain *a* passes over a differential pulley *b*, and about a single-chain pulley *c* at the bottom. A hook is attached to each pulley, the upper one *d* being used to support the block from the ceiling, or overhead part, and the lower one *e* for the purpose of taking hold of the part to be raised. The differential pulley *b* is provided with two chain grooves, the diameter of one being greater than the diameter of the other. As the chain is drawn over the pulley so that the latter revolves, a greater length of chain per revolution will travel over the groove with the larger diameter than over the one with the small diameter. This being true, it will be seen that when the side of the loose loop *a*, which is on the large diameter, is drawn down, it will shorten the distance between the two pulleys and lengthen the loose loop. By drawing down on the other side of the chain that runs over the small diameter, the distance between the pulleys is increased. A weight hanging upon the hook *e* will be raised or lowered according to which side of the loop is pulled. Other forms of chain blocks, in which the reduction is obtained with worms and worm-gears, or by means of spur gears, are also used quite extensively.



FIG. 24.

89. Pneumatic Hoists.—Shops provided with a compressed-air plant use the air for many purposes. It is particularly useful in serving work to the machine tools, vise, bench, laying-out table, etc. The principal features of this hoist, which are shown in Fig. 25, are a cylinder *c*, in which slides a piston

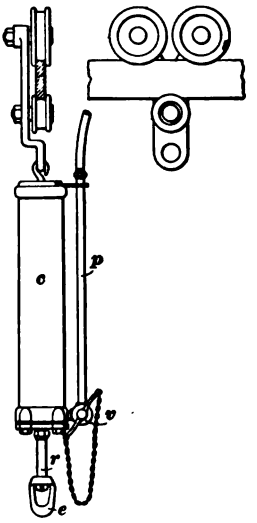


FIG. 25.

having a rod that is supplied with an eye *e* at its lower end. The air pipe is connected to the air-pipe line by a hose, and air is admitted to the cylinder by the three-way cock *v*, which is operated by the chain in order to raise the weight that is attached to the eye. The hoist will lift the length of its piston travel and will travel on its runway as far as the hose will permit.

CRANES.

90. Jib Crane.—Limited areas, and often one or two machine tools, are served by jib cranes, one form of which

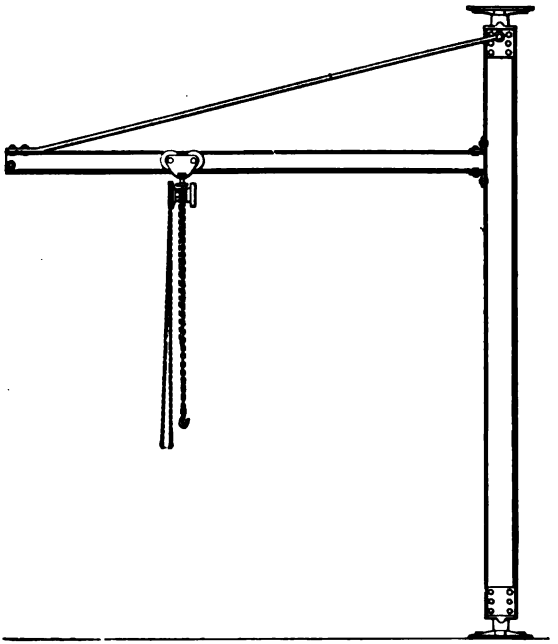


FIG. 26.

is shown in Fig. 26. Heavy cranes of this type, capable of lifting 30 tons, are in use in some shops, although for such heavy work the traveling crane is generally preferable.

91. Trolley System.—The traveling hoist furnishes an extremely useful and convenient method of handling

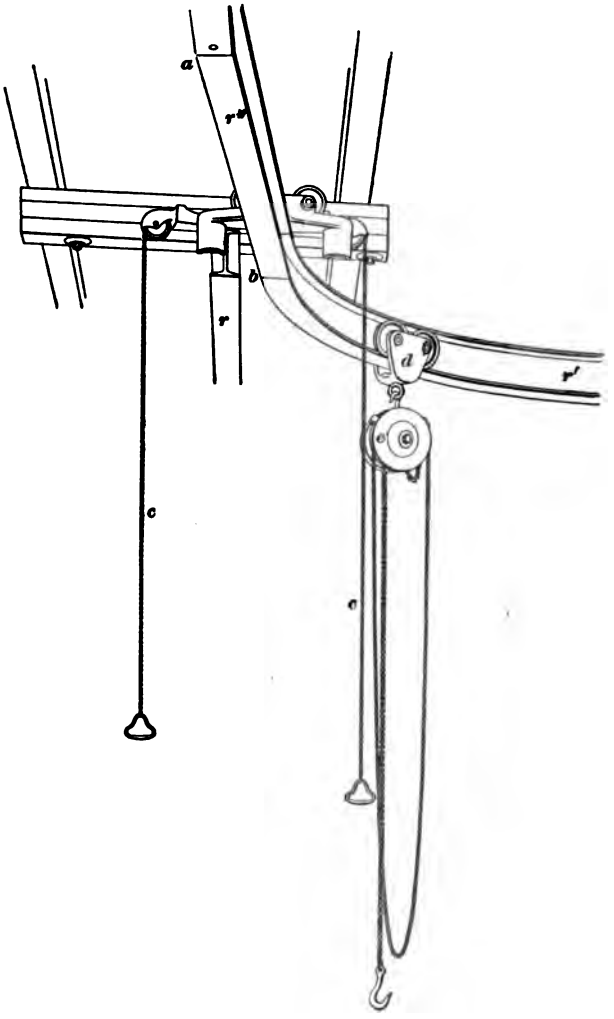


FIG. 27.

light and medium-heavy work, and it is especially adapted to shops having low ceilings in which the traveling crane

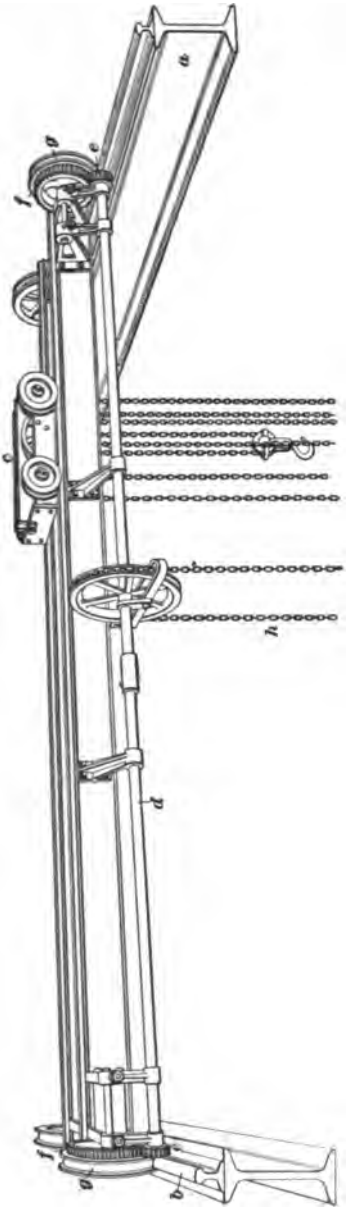


Fig. 27.

cannot be used. The runway or track used in this system of shop transportation consists of **I** beams suspended from overhead, as shown in Fig. 27.

The illustration shows how the traveler *d* may be switched from the main track *r* to a side track *r'*. A section *r''* of the main track is hinged at *a*, and its free end can be swung in line with the main track or side track by pulling one of the chains *c*, *c*. The hoist *e* is attached to the traveler.

92. Hand Traveling Crane.—The traveling crane furnishes the most modern and convenient means of shop transportation. Cranes of this kind are operated by hand, by power-driven shafting, or by electric motors.

The traveling crane is a bridge-like structure, spanning the floor and supported on steel rails placed on suitable supports, as is shown in Fig. 28. This crane has a capacity of from 2 to 6 tons and is operated by hand. It is built for spans

of 30 feet and under. I beams *a* carry the rails *b* on which the crane runs. In the case of heavy cranes, these I beams are replaced by built-up girders. These runways are placed as high up in the building as possible in order to get as much room under the crane as can be had. The runway extends the whole length of the floor or building and a trolley *c* running on rails can travel from one end of the bridge to the other, and hence can be brought over any desired point on the floor. Hand cranes like the one illustrated are operated from the floor in the following manner. A shaft *d* has a pinion *e* on each end that meshes with the gears *f*, *f*; they are keyed to the same shafts to which the wheels *g*, *g* are fastened. The shaft *d* is rotated by pulling the chain *h*, and the crane is thus traversed lengthwise of the building. A similar mechanism runs the trolley from one end of the bridge to the other. The hoisting is done from the floor and provision is made for several men to work the hoist for heavy loads.

93. Power Traveling Crane. — The power-driven and electrically driven traveling cranes have the same general movements as are found in the hand crane just described, but as they are intended for heavy work they are built heavier than the hand cranes. The power-driven crane is usually operated by means of a square shaft placed just below the bridge and close to the runway girder. This shaft is carried in boxes at each end, and, passing through a sleeve that is attached to the crane, it transmits its motion to the various trains of gearing that operate the different traverses and hoists. The great length and weight of the square shaft makes it necessary to furnish more support than is afforded by the boxes and the sleeve. The additional support is given in the following manner. The shaft is made in sections, with cylindrical bearings turned at regular intervals for the supports, which are placed under it. These supports automatically drop down out of the way as the crane comes to them and return to their places when the machine has passed along. The square shafts are made in as long

sections as can be shipped, and are welded together in the shop where they are to run and then hoisted into position.

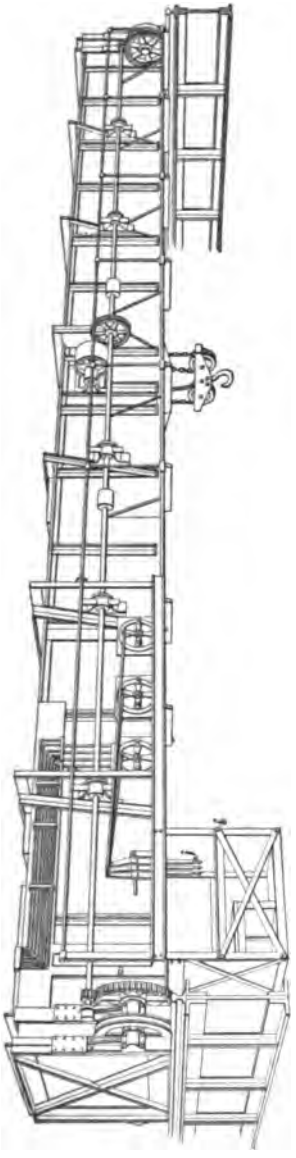


FIG. 29.

94. Electric Traveling Crane.—The electrically driven crane may be driven by a single motor and the separate parts may be run by trains of gearing, but more generally it has a separate motor for each movement. Many such cranes that are intended for heavy work have an auxiliary hoist in order to allow light work to be handled much quicker than can be done with the main hoist.

The current for operating these cranes is taken from wires run along the sides of the building just above the bridge. The operator is carried in a cage *i*, Fig. 29, suspended below and to one side of the bridge, where he controls the various movements by means of levers, switches, or other devices shown at *j*.

95. The crane illustrated in Fig. 29 is electrically driven, and has a capacity of 10 tons, with a span of 54 feet; the same general manner of construction is followed by its builders in the construction of similar cranes that will lift as much as 150 tons.

ERECTING.

(PART 2.)

MACHINE ERECTION.

LATHES.

1. Systems of Lathe Erection.—The method of erecting lathes varies greatly in different shops and also with different sizes and designs. Some makers first plane the grooves in the headstocks and tail-stocks to a gauge and then bore the boxes of the headstocks and the holes for the tail-stock spindles, while others reverse the operation, first boring the boxes and the holes in the tail-stock spindles and then planing the grooves in the bottoms of the headstocks and tail-stocks. Both systems, or modifications of both, are frequently used in the same shop. The second system is generally used on small lathes, up to 18 inches swing, while in the case of larger lathes the first-mentioned system is more common.

2. Seasoning the Beds.—Where extremely accurate lathes, such as toolmakers' lathes, are to be made, the beds should be cast several weeks before they are to be used, and allowed to season. This consists in simply piling them in some convenient place in such a way that they will not be subjected to any outside forces, and allowing the stresses in

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the casting itself to become equalized. Where extremely accurate work is required, a roughing cut is taken off the surfaces to be planed and the beds are again allowed to season for a short time before being finished.

3. Machining the Beds.—Lathe beds may be finished either on the planer or milling machine. For more accurate beds, especially for larger sizes, planing is preferable. The V grooves, guides, or shears are usually planed to gauges. The outside edges of the bed and the flat top between the ways are also planed. After the work leaves the planer, the space between the grooves, the outside edge, and the flat top of the bed should be filed and polished as soon as possible, on account of the fact that they can be finished much easier and in less time immediately after planing than would be possible if the work were exposed to the air of the shop for some time. The reason for this is that the file takes hold of the freshly planed work better than it does after the surfaces have become slightly rusted. Some persons claim that the reason a file does not take hold of the surface of a casting that has stood for some time after planing is that the surface becomes covered with a thin coating of grease that is deposited from the air of the shop.

4. Testing.—The ways are usually tested by a straightedge and then scraped, or, if necessary, they are filed and scraped. However, one of the best shops, in which small

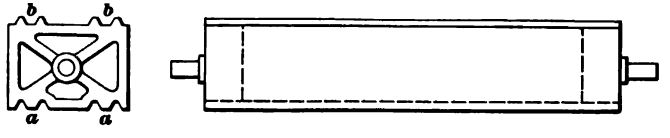


FIG. 1.

lathes are made in lots of from 25 to 100 at a time, uses a special surface plate made as shown in Fig. 1 for each size of lathe. This surface plate has been fitted up with great

care, so that both the top and bottom ways *a* and *b* match each other; it has a trunnion at each end and can be lifted by a bale attached to a chain block or air lift. The trunnions permit the plate to be turned with ease, either side up. The ways on the lathe bed are scraped to fit the grooves *a*, *a*, and the headstock, tail-stock, and saddle are scraped to fit the ways *b*, *b*. The saddle is sometimes scraped to the ways on the bed.

5. Machining and Fitting Headstocks and Tail-Stocks.—The headstocks and tail-stocks of small lathes are frequently made ready for the boxes and caps by milling, while the larger sizes are planed, machining them if possible by the gang system; that is, a large number are put on the planer table in line, and all are machined together. Jigs are usually provided for holding the pieces on the milling machine, and may also be employed on the smaller sizes when the work is done on the planer. The legs are fitted and bolted to the bed at any convenient time, but it is generally done before the ways on the bed are scraped.

The machined castings for the headstocks and tail-stocks are next sent to the fitter; the boxes and caps are then fitted to the headstocks, and the tops and bases of the tail-stocks are fitted to each other.

6. Boring for Headstock and Tail-Stock Spindles. There are two general systems for boring the holes for the spindles in lathe headstocks and the tail-stocks. In the case of small lathes, the boring is usually done first, after which an arbor is placed in the bored holes of both headstock and tail-stock. This arbor is made to fit the holes in both accurately, and hence serves to bring them into line. While the pieces are held in line by means of the arbor, the V grooves are planed in them. In the case of larger lathes, the V's are usually planed first and the headstock and tail-stock fitted to the ways on the bed. After this a special fixture carrying a boring bar is used for boring the holes in the headstock and tail-stock. This fixture is constructed so that it

holds the boring bar parallel to the V's or ways of the lathe. A special jig may be used for holding the headstock and tail-stock while boring, in place of putting them upon the bed. After the boring is completed and the V's are planed, the work of erecting actually begins.

7. Erection and Inspection of Lathes. — Lathe erection differs somewhat in different shops, but the following may be taken as a good illustration of the general method of procedure. The bed, with the legs attached, is placed in position on the erecting floor and leveled until it is out of wind. The V's or ways are tested by means of straightedges and suitable gauges. The headstock and tail-stock are then scraped to fit the V's.

When the headstock and tail-stock have been brought to fit the V's fairly well, their spindles are brought into alinement. This is commonly done by means of proof bars, as

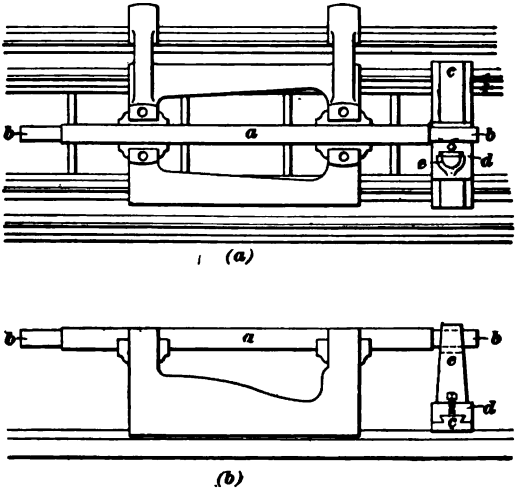


FIG. 2.

shown at *a*, Figs. 2, 3, 4, and 5. These proof bars fit the boxes of the headstock and the bore of the tail-stock spindle. The ends *b* of the proof bars are finished by grinding to

exactly the same diameter, so as to allow them to be used in making measurements for alinement. A temporary saddle *c* is used for this purpose. It is provided with a groove fitting one of the V's of the bed, and carries a slide *d* to which an upright arm *e* is fastened. The headstock and tail-stock with the proof bars in them are placed on the bed some distance from the ends. The temporary saddle is placed near one end of one of the proof bars, and the slide *d* is adjusted until the feeling piece, as, for instance, the steel rule *f*, shown in Fig. 3, will just fit between the face of the upright *e* and the end *b* of the proof bar. The saddle *c* is then shifted to each end of each proof bar, and the distance between *e* and the ends *b* of the proof bars tested in each position. This is done without disturbing the position of the upright. The manner in which the feeling piece goes in shows whether the headstock and tail-stock are in perfect alinement in a horizontal plane. If this is not the case, the grooves that fit on the V's of the lathe are scraped until the piece that is out of alinement is brought into perfect alinement. Sometimes a machinist's indicator or some form of micrometer head is carried on an upright *e*. Such a device as this serves to measure the amount that the spindles are out of alinement.

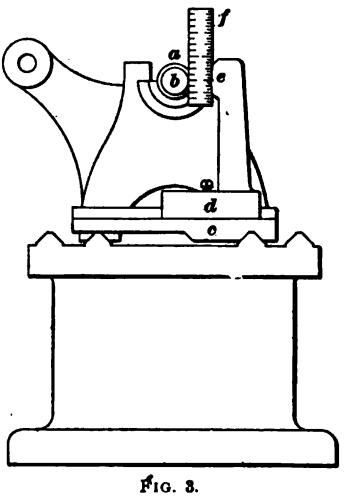


FIG. 3.

8. To test the vertical alinement of the spindles, a jack *g*, Fig. 4, may be used. This is placed on top of the parallel *c* and is tested by adjusting the screw until it will just touch one end of the proof bar. The parallel and the jack are then shifted to each end of each proof bar. The manner in which the jack goes under the bar determines which way, if any, either end of the spindle is out of line.

The method of testing the alinement which has just been

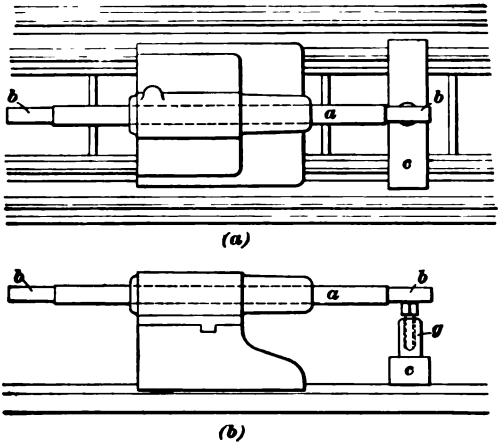


FIG. 4.

described not only tests the alinement of the headstock and tail-stock spindles in respect to each other, but at the same

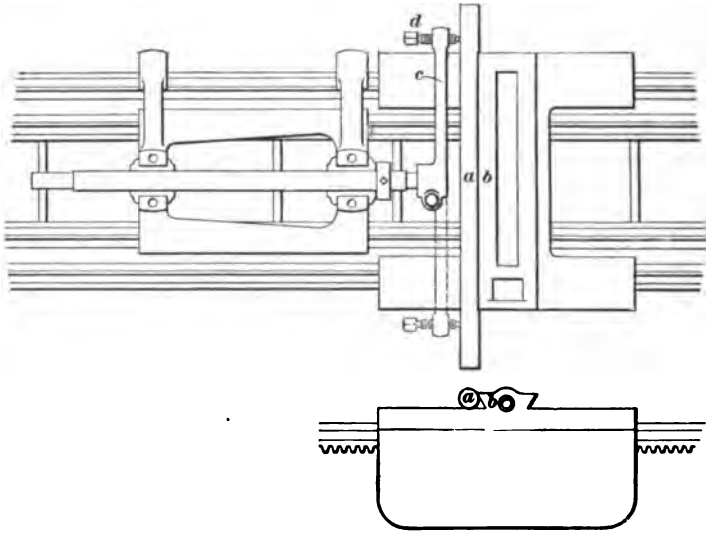


FIG. 5.

time tests their alinement with the ways or line of motion.

After the headstock and tail-stock are lined, the saddle is placed on the V's and a round test piece *a*, Fig. 5, is placed against the slide *b*. This test piece should be ground exactly cylindrical and should be long enough to project several inches beyond the sides of the saddle. An arm *c* is now fastened to the proof bar and the setscrew *d* brought in contact with the bar *a*. The proof bar is then rotated to the opposite side, to the position shown by the dotted lines. If the screw *d* does not show the saddle to be square, it must be shifted by scraping the V's in the saddle until the slide *b* is at right angles to the V's, as shown by the test bar *a* and screw *d*.

After the headstock, tail-stock, and saddle are brought into alinement with the V's, the tail-stock spindle and anchor are added to the tail-stock, and the spindle, back gears, feed-mechanism, and feed-reversing mechanism are placed in position on the headstock. It is necessary to have the set-over screws in the tail-stock while lining the tail-stock spindle if the two spindles are to be brought into line with each other.

9. The apron is next clamped to the saddle and tested for alinement by using a proof bar placed in the bearings for either the lead screw or feed-rod. Measurements for alinement are taken from the bar to the edge of the bed and to the top of the bed. If necessary, the apron is brought into alinement by filing its top and back. The apron is then secured in position by screws, and the boxes for carrying the lead screw and feed-rod are placed on special bearings provided on the ends of the apron proof bar. The boxes are then moved into contact with the pads on the bed, which have been provided to carry them. These pads have been previously planed, and the boxes are marked and then planed to fit on the pads. After the boxes have been planed they are fastened to the bed, and the feed-rod, the lead screw, and the remainder of the feed-mechanism and screw-cutting mechanism are put in place.

10. Taper Holes in Headstock Spindles. — The taper hole for the center of a live spindle is put in by different

methods; its accuracy is in some instances very intimately connected with the assembling or erection processes. Some makers prefer to rough out the spindle, particularly if it is a small one, and then to drill, ream, and hand ream the hole, after which the spindle is centered by the hole and trued outside, a plug having been fitted to the taper hole.

Another method that has many advantages is used extensively for large spindles. The spindle is centered and a steady rest seat is turned on both ends, if it is to be a hollow spindle; the hole is then put through. Plugs are driven into both ends if the hole is larger than an ordinary lathe center, and the spindle is finished with the exception of the face-plate thread and the taper hole. The assembler or erector puts the unfinished spindle into its place, and if a large number of headstocks are to be finished, he puts them successively on a lathe bed made for the purpose and provided with a taper attachment, and bores the taper hole true, smoothing it with a hand reamer. He completes the work by cutting the thread to fit the face plate. In large lathes that are not built in large quantities, the headstock is mounted on its own bed for boring the taper hole in the spindle and for cutting the thread; a compound rest is used for boring the hole in case the lathe has no taper attachment. The process in which the spindle is finished in its own bearings has the important advantage that with reasonable care and skill on the part of the erector the taper hole and the thread will be concentric with the bearings of the spindle.

11. Inspection.—All machines are more or less defective, as it is practically impossible to make anything absolutely perfect. Knowing this, the builder establishes a limit within which the error will not materially affect the working of the machine, and furnishes the inspector with a list of such defects and their limits, with instructions not to allow a machine to pass until the errors have been brought within the allowable limits. The principal features of an inspection prior to shipment are here given and are followed by a specimen of an inspector's report.

12. The hole in the headstock spindle is tested for concentricity by means of a proof bar. This bar is ground tapering to fit the hole in the spindle and is cylindrical the remainder of its length. It may project a foot from the spindle for the smaller lathes and more, proportionately, for the larger ones. By revolving the spindle and applying the indicator to the bar at the mouth of the hole and again at the outer end, the amount of error is easily determined.

The alinement of both spindles in reference to each other may be tested by means of the pair of disks shown in Fig. 6, which are made with taper shanks *a*, *a* that fit the taper holes in both spindles. The disks *b*, *b* are ground to the same diameter and are faced as square as possible. They are placed one in each spindle; the tail-stock is then moved up to the headstock and when the faces *c* of the disks are brought nearly in contact, the amount of error is shown by looking through both vertically and horizontally.

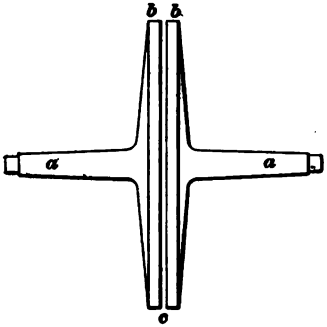


FIG. 6.

A pair of centers, having their ends beyond the taper, cylindrical and exactly to the same size, with the ends faced square, are sometimes used by the erector to determine if the spindles are in line. One is placed in each spindle, and when the two are brought up end to end, show very closely if there is any error in alinement.

13. The leadscrew is particularly liable to error. This is tested for any deviation from the true pitch in lengths of 12 inches at different points along the screw. Gearing of all sorts is inspected and tested for alinement and smoothness of operation. The fits of all wearing surfaces are tested, as well as the fit of the various screws and binding and clamping fixtures. No part is neglected, and no defective material or faulty workmanship is allowed to pass.

14. Inspector's Report. — The inspector is usually provided with a printed blank for reporting each lathe. The serial number is stamped on the lathe and this appears on the report, which is filed in the office for use should complaint be made or repairs ordered. Such a report is appended.

INSPECTOR'S REPORT.

16" X 6' Compound Engine Lathe.

Lot No. 1300 Inspection No. 1903

Spindle runs at mouth, 1/1000

" " end of 12-inch bar, 1/1000

" lines with ways, Ver. 1/1000 Hor. 1/1000

Tail Stock " " " "

Test piece for boring 8 inches, shows large at front end } 0

Face Plate squares up concave, 1/1000

Taper Attachment Slide Ways with Ways on Bed, }

Back Gears run, Good

Chuck runs,

Rest Binder Good

Lead Screw, per foot 2/1000 long in one foot

Ordered by

Worcester, Mass., U. S. A., Sept 17 1900

J. S. L. Inspector.

PRENTICE BROS. COMPANY.

PLANER ERECTION.

15. Systems of Planer Erection.—In planer erection the principal points to be considered are that the system must be such as to quickly and cheaply assemble the parts so that they will all be in their proper relation to each other and that the alinement of the various parts will be perfect within the required limits. Small planers can be erected

much easier than large ones, owing to the fact that there is very little or no appreciable spring in their beds. When manufacturing small planers, it is possible to make the parts so accurately by means of gauges and templets that they can be assembled and made practically interchangeable. In the case of large planers, it is impossible to make the parts interchangeable, on account of the fact that the bed depends on the foundation for its support, it being impracticable to make a casting large enough to insure perfect rigidity in the bed. For this reason, in the case of large-sized planers, it is necessary to treat each machine by itself. All the points in the erection of a small planer are involved in the erection of a large planer, and many other complicating factors come in; hence, the erection of a planer of this class will be given in detail.

16. Classes of Planers.—For convenience in treatment, planers may be divided into three classes: small, which plane up to 24 inches square; medium-sized, which plane from 24 to 40 inches square; and large planers, which plane larger than 40 inches square. Small-sized planers are usually provided with a single head for carrying the tool, the head being placed on the cross-rail between the housings. Most medium-sized planers have but a single head, although some of the larger ones are provided with two heads on the cross-rail. The larger planers are all provided with two heads on the cross-rail and with one head on each upright.

Planers may also be divided into two classes in regard to their construction; that is, into those having double housings, or closed planers, and those having but one housing, or open-side planers. The erection of either type, as far as the general principles are concerned, does not differ greatly, and the erection of the closed type involves the bringing of the housings parallel, and hence planers of this type will be considered. In the case of planers that are intended to plane 120 inches and upwards, provision is frequently made for handling the work that will not pass between the housings at all. This is accomplished by placing a floor plate on

one or both sides of the bed about half way between the front of the housings and the end of the bedplate. A post or posts are located on this floor plate and provided with vertical guides carrying one or more heads. These uprights can be moved toward or away from the planer bed, and the heads carrying the tools can be fed up or down the uprights. This provides for the planing of surfaces at right angles to the face of the table or very large work. With this device the casting rides back and forth on the table. When the castings are still larger, they are sometimes placed on the floor plate, and the tools are carried by heads placed on the uprights bolted to the planer table, the work standing still and the tool being moved with the planer table.

17. Precautions in Regard to Castings. — All castings for planers should be made from good close-grained iron. The castings for the table should be of a soft but tough nature, so that the upper surface can be planed true at one setting of the tool, for if the casting were hard it would wear the tool enough to throw the surface appreciably out of true. Very large planer beds, and occasionally large planer tables, are made in two or more pieces and joined by means of bolts and dowel-pins.

18. Precautions Necessary in Machining.—All the larger castings for the planer should be planed to carefully tested gauges, and every angular surface tested to make sure that the angle is correct. The work should be tested with a straightedge on the machine to make sure that the planer is not working concave or convex. Care taken in planing these parts will reduce the work of the fitter and erector. Long beds or tables that are made in sections should have their ends planed perfectly square and should be bolted together as securely as possible with fitted bolts and dowels. After all machine work is done, the erection proper begins.

19. Supporting the Bed.—The bed *a*, Fig. 7, is supported on cast-iron parallel blocks *b* placed 6 or 8 feet apart

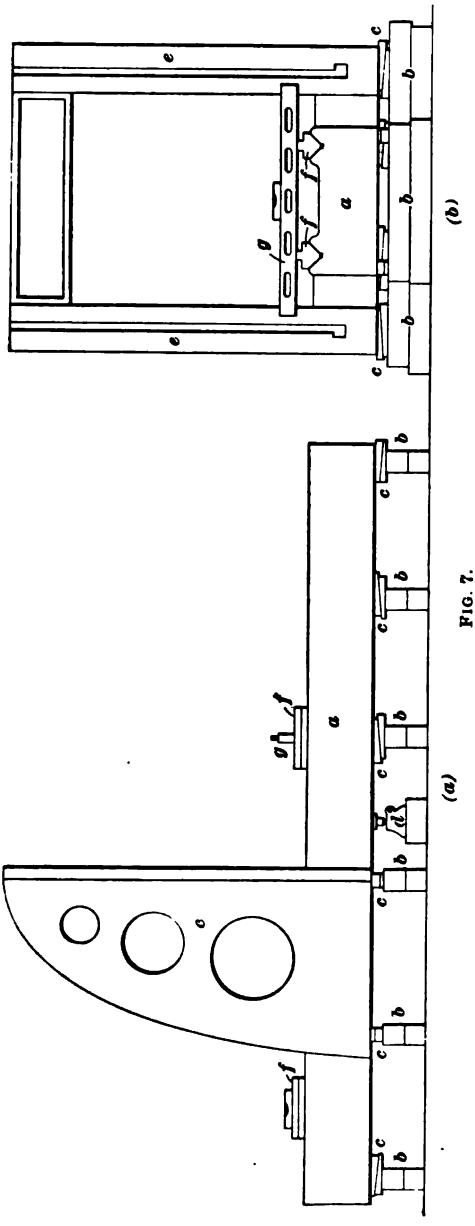


FIG. 7.

along the whole length of the bed. Planed cast-iron wedges *c*, arranged as adjustable parallels, are placed between the parallel blocks *b* and the bed. A clamp jack *d* is placed under the bed at each side just forward of the housings. This may be removed if necessary while putting in the driving gearing. The arrangement of all the blocking under the uprights should be such that none of it will interfere with the driving and feed-mechanism during erection. As these details vary in different machines, the blocks must be arranged to suit each different machine. It is best to put the uprights *e* in their places on the bed before the leveling operation, as the addition of their weight is liable to throw the bed

out of level again if they are placed in position afterwards. In some cases the uprights *e* are supported on erecting jacks in place of blocking, as this facilitates adjustment of the parts during leveling.

20. Leveling the Bed. — Several methods may be followed in leveling a planer bed, depending on the tools at hand. They all require considerable care. The process here described will give very good results if the work is carefully done. The leveling is done as follows: A pair of V-shaped parallels *f*, about 3 feet long, are placed one in each of the ways or V's of the bed. These parallels have been scraped as nearly true as it is possible to make them, and they may have center lines on them. A sensitive level is used on the top, and one side of the bed is carefully leveled by moving this parallel, short distances at a time, over the entire length. The other parallel is used in a similar manner in the other V, and by placing a straightedge across both of the parallels and using the level on it, the work is leveled crosswise. The operation of first leveling one side and then cross-leveling to the other is repeated several times, or at least until no further errors can be detected.

21. Setting the Housings.—The housings are now tested and brought exactly plumb by placing a straightedge across the blocks lying in the V's and using a large square on the straightedge. In the case of large planers having a very heavy cross-rail and heads, some makers do not attempt to bring the housings exactly plumb on their faces, but allow them to lean back $\frac{5}{1000}$ inch for every foot in height, as the weight of the cross-rail and heads will bring the housings forwards somewhat, and experiment has shown that this allowance will about correct the error from this cause. The housings are squared both sidewise and in front, and the distances between them at the top and bottom are made equal.

In gauging these distances on a large planer, use may be made of the device illustrated in Fig. 8 (*a*), which consists

of a wooden bar made of white pine or some other light wood, and fitted with screws at each end. The wooden bar should be 1½ to 2 inches shorter than the distance between the housings, and the screws may be simply 2½-inch wood screws with their heads filed off and the ends pointed and rounded, as shown in detail in Fig. 8 (*b*). The wooden stick may be tapered from the center toward both ends, and in the case of a rod for measuring a distance of approximately 10 feet, the wooden strip would have to be about 1½ in. × 2½ in. in the center. The advantages of the wood are that it is lighter than metal and that it is not affected so much by expansion and contraction due to varying degrees of temperature. This distance between the housings on a large planer is not made any fixed distance, the only object being to make it the same at the top and the bottom, and hence this device becomes only a large inside caliper.

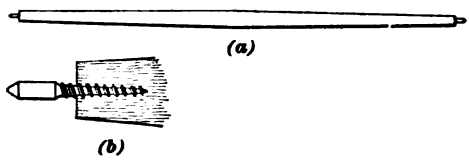


FIG. 8.

During the operation of setting the housings parallel, the gauge is set to the smallest distance, whether it be at the top or bottom, and is then transferred to the wider end, the amount it is necessary to move the housings being determined by introducing pieces of sheet metal or paper between the screw and the casting. By measuring these pieces with the micrometer, it is possible to tell just how much the housing must be moved.

After the housings are perpendicular and parallel, the girder or top rail is squared off to the length indicated by this gauge and bolted in position. In the case of large planers, no attempt is made at interchangeability in this respect, but each top cross-rail is fitted to its individual planer.

22. Placing the Table and Driving Mechanism. The ways on both table and bed are fitted to a good bearing

by scraping to surface plates. The driving mechanism is put in place. The table may then be put in place also, and any scraping necessary to true it to the ways is done, after which the thickness of the table rack is determined; the rack is planed to the required thickness and secured to the table.

23. Squaring the Cross-Rail.—The cross-rail must be set true to the V's in which the planer table slides. One manner of accomplishing this is illustrated in Fig. 9. The table *a* is run back far enough to expose the V's under the cross-rail and two cylindrical pieces *b*, *b'* of exactly the same diameter are introduced into the V's. A square-nosed tool *c* is placed in the tool post and brought over one of the cylinders *b*. The tool is then tested until the feeling piece can just be moved between the cylinder and the tool. Another method is to use a machinist's indicator in place of the tool, and bring the point of the indicator in contact with the cylinder. The tool or indicator is now run to the opposite side of the planer and adjusted over the cylinder *b'*. If *b'* is found to be higher or lower than *b*, the error must be corrected by adjusting one end of the cross-rail up or down. Some makers find that a sufficiently close adjustment can be obtained by moving one of the gears *k* or *k'* one tooth, so as to raise or lower one end of the cross-rail this amount. If this adjustment is not close enough, a small amount may be scraped off the hub of one of the gears. Other makers leave one of the pinions *m* or *m'* loose until the adjustment has been made, after which they key it in place. Still others attach one of the pinions, as *m'*, by means of a setscrew, as shown at *n*.

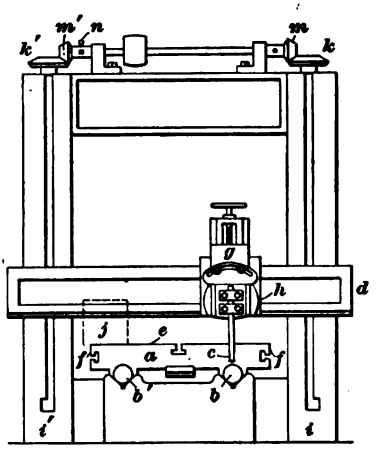


FIG. 9.

The cross-rail is moved up and down by two screws operated by the gears k and k'. When one end of the rail is found to be low, it should be raised the proper amount. In Fig. 9 this can be accomplished by loosening the screw n and turning the gear m' the desired amount. By repeating these trials the cross-rail can be brought into such a position that the tool and feeling piece, or indicator, will give the same reading over both cylinders b and b'. The vertical screws carrying the cross-rail should always be adjusted in such a manner as to raise the cross-rail, on account of the fact that this will take up any lost motion or backlash between the nuts, the feed-screws, and the uprights. For this reason it is always better to raise the low end of the cross-rail rather than to lower the high end. The feed-mechanism and the mechanism for raising the cross-rail by power, together with the oiling device, are all put in place and tested, after which the machine is tested to see that it is within the allowable limits of error.

After the cross-rail has been adjusted parallel to the V's, a light cut should be taken over the top of the table. The head g should then be set vertically by means of a square. In the case of very large planers the table is not trued in place by the manufacturer.

24. Preparation of Planer for Shipment.—Small and medium-sized planers are generally shipped with the principal parts in place and all bright parts coated with a slush of oil, or some other protective coating, to prevent rusting. The lighter and small parts are crated to prevent breakage and the whole mounted on skids for convenience in handling. Larger planers are taken apart, the smaller pieces being boxed and the fitted faces of the larger ones crated. All finished surfaces, in all cases, are slushed or given a protective coating before shipping. The smaller planers have their tables carefully trued in place before leaving the manufacturers, but the larger ones are usually shipped with the table just as it comes from the planer on which it was finished.

ERECTION OF PLANERS IN PLACE.

25. Large Planers.—In the case of all large planers, the beds of which rest on the foundation, the bed is placed on the foundation and leveled by means of wedges or jacks. The housings are bolted in place and the bed leveled by the process described in Art. **20.** The housings are also set perpendicular to the bed. The cross-rail and its elevating mechanism are then placed in position.

The cross-rail may then be tested to see that it is parallel with the V's, as described in Art. **23.** The feed-mechanism may be put in by other men while these operations have been going on, and after the cross-rail is adjusted parallel to the V's, the table should be tested. If it is found that the table is not parallel with the cross-rail, a light cut should be taken over it. After this is accomplished, the head *g*, Fig. 9, must be set to plane perpendicular. In the case of a large planer there will probably be two heads on the cross-rail. They are both set as near perpendicular as possible by means of a square. After this, the sides *f*, *f* of the table may be trued down by means of tools set in the heads, and the angle at the edge of the table tested by a square. If this is found to be true, the mark *h* is placed on the saddle opposite the zero mark of the graduations on the head, as practically all planers are shipped from the factory with their heads graduated, but without the zero mark on the saddle being located.

If the planer is provided with side heads on the uprights *i* and *i'*, they may be tested by bolting a casting as indicated by the dotted lines at *j* to the face *e* of the table and then taking cuts from the sides of this casting by means of the side heads, the upper face of the casting having been trued by means of a tool in one of the heads on the cross-rail.

26. Securing the Planer to the Foundation. After the planer is erected and all the tests have been made and everything adjusted correctly, it should be secured to the foundation. This may be accomplished by ramming any suitable cement between the bottom of the bed and the

top of the foundation. Sometimes iron chips and sal ammoniac are used. In other cases a regular Portland cement mortar is employed, while in some cases melted sulphur is poured under the bed. After the cement is in place the planer should not be used until time has been given for the cement to harden. In cases where the foundation is on yielding ground, and it is not practicable to obtain a permanent foundation, planers are sometimes left set on wedges or jacks and are leveled up frequently to keep them in line.

The bed of the planer should be tested lengthwise with a straightedge to see whether or not it is planing concave or crowning. This precaution is especially necessary in the case of very long planers. It is convenient to have the planer table set level so that a spirit level may be used on any part of it. In this case, by applying the spirit level to different parts of the table it will indicate whether the planer is planing convex or concave.

27. Planers Having Legs.—Small and medium-sized planers are shipped from the factory with all their parts in place, and hence do not need as careful attention in erection as do the larger sizes, which have to be assembled on their foundations. It is usually sufficient to drive wedges under the legs until the table is level. The cross-rail is then tested to see that it is parallel to the top of the table, and if found so, no further adjustment need be made. If it is not parallel, the table should be run back, and the cross-rail set parallel to the V's, as described in Art. **23.** After this, a light cut should be taken over the table and the heads set to plane vertically.

In the case of very small planers, the beds are usually stiff enough so that very little, if any, adjusting is necessary when setting them up, all the adjustment being made by the manufacturer; but even in this case it is well to go through the entire series of tests, if accurate work is to be required from the machine.

28. Setting Planer Heads.—The amount of accuracy required in setting the heads, either on a large or small

planer, depends very largely on the character of the work to be done on the machine. If the work will all be simply roughing and surfacing, the zero mark *h*, Fig. 9, may be placed accurately enough by adjusting the head to any available square and scribing or cutting the mark on the saddle; while if a large amount of angular work is to be done on the planer, it will be necessary to face down one or more castings to see that the mark is accurately located. Sometimes it is well to put on a provisional or temporary mark and then test each piece of work as it comes from the planer until sufficient information has been obtained to locate the mark accurately.

MILLING-MACHINE ERECTION.

29. Introduction.—There is a large class of machines in which the erection cannot all be done at one time, but must be carried on between the various operations in the machine work. This is on account of the fact that some parts of the machine must be completed before other parts can be machined or fitted. This is especially true of very large machines and of some comparatively simple machines in which a number of parts are interdependent. The milling machine as erected in at least one large shop forms a good example of this class of erection.

30. Planing the Column.—The column *a*, Fig. 10, is first fastened on a planer table with the face *b* up. Great care must be taken to see that the casting is not sprung by clamping. The face *b* and the inclined surfaces *c*, *c'* are carefully planed to a standard gauge. The general form of these parts is shown in Fig. 11.

31. First Drilling Operation.—After the planing is complete, the frame is taken to a drill press and all the holes that do not require exact location drilled. This includes those for fastening the column to the floor, for the tool shelf, the tool-cupboard door, etc. A special jig that clamps on to the face *b* by means of the surfaces *c* and *c'* is used to guide drills and reamers for forming the holes for

the elevating screw *d*, the knee stop-rod *e*, and the vertical feed-shaft *f*. This jig must not be confused with the large drilling and boring jig described later, but is simply an

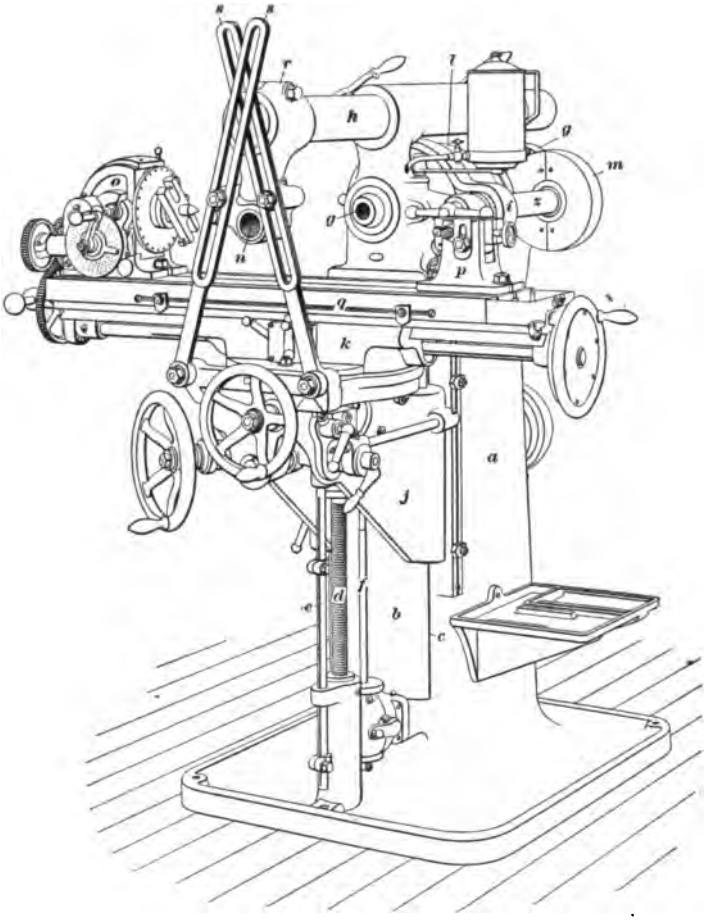


FIG. 10.

angle plate that is clamped to the face *b* and carries bushings for locating the holes mentioned.

32. Fitting the Surface for Carrying the Knee. After the first drilling operation is completed, the column is

laid on its back and the surface *b*, Fig. 10, scraped to a surface plate. After this, the angular surfaces *c* and *c'*, Figs. 10 and 11, are scraped to a special surface plate or straightedge of the pattern shown in Fig. 12. The exact angle between the surfaces has to be determined by means of a gauge. The surfaces *a* and *a'*

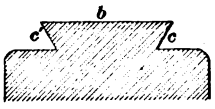


FIG. 11.

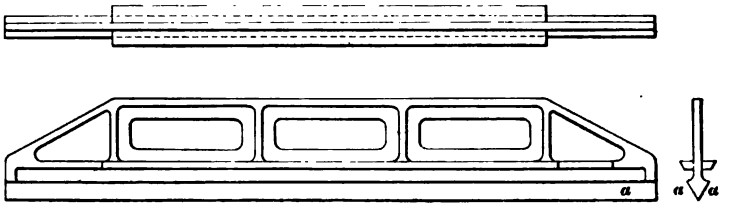


FIG. 12.

of the straightedge are scraped and fitted perfectly true.

33. Painting the Column.—After the scraping is complete, the surface of the casting is filled, rubbed down, and painted, all but the finishing coat being applied at this time. The finishing coat is not given until after the machine has been inspected.

34. Boring Operations on the Column. — After the scraping is completed, the column *a* is placed in the jig *b*, Fig. 13. The surface *b*, Fig. 10, rests on a scraped surface in the jig, and the surfaces *c* and *c'*, Figs. 10 and 11, are brought in contact with the gibs in the jig, the fixed gib being shown at *c*, Fig. 13, and on the opposite side there is an adjustable gib that is held in position by means of set-screws. This secures the column in its proper relation to the jig, after which the holes for the spindle *g*, for the supporting arm *h*, and the back gear-shaft *z*, Fig. 10, are all bored in their proper positions. While these holes are being bored, the boring bar is supported at each end in hardened-steel bushings, and is driven by means of a floating driver carrying two universal couplings. This method of driving the boring bar prevents all danger of the spindle of the drill press springing it out of line with the bushings. The holes

are both bored and reamed while the column is held in the jig. This method of procedure insures the holes mentioned

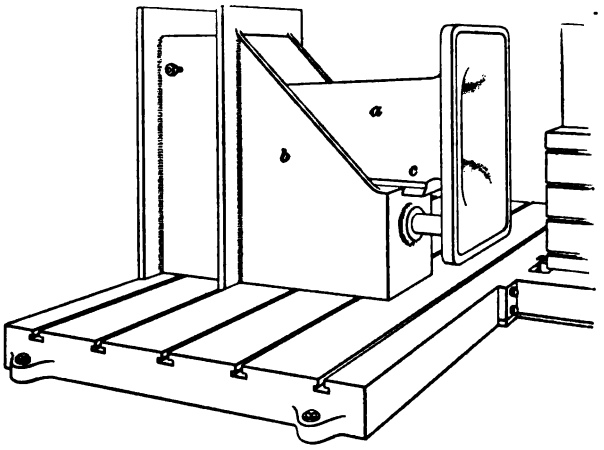


FIG. 18.

being at right angles to the face *b*, Fig. 10, and hence in the proper relation to the table.

35. Fitting the Various Parts.—After the holes for the spindle *g*, the supporting arm *h*, and the back gear-shaft *z*, Fig. 10, have been bored and reamed, the column is removed from the jig and placed in an upright position on the floor. The boxes in which the spindle runs are then fitted in place by grinding.

The knee *j*, Fig. 10, is planed up and its upper face scraped to surface plates in a manner similar to that used in scraping the surfaces *b*, *c*, and *c'*, Figs. 10 and 11. The face that is to fit the upright of the column is also fitted, and care must be taken to see that these two surfaces are at right angles to each other. After this the knee is fitted to the upright by scraping the upright face of the knee until the horizontal face comes square with the surface *b*, Fig. 10.

The spindle that has been accurately ground with tapered bearings is now fitted into its place by scraping the boxes to bring the spindle true with the top of the knee. Care should be taken to see that the spindle is true in both the

horizontal and vertical planes. The scraping also serves to give the spindle a good bearing in the boxes.

After the knee and spindle have been fitted up, the clamp bed *k* and the table *q*, Fig. 10, are fitted in place, each one being adjusted to the parts already in place. The index head *o* and tail-stock center *p* are fitted up elsewhere and placed on the table after it has been accurately fitted.

The overhanging arm *h* is fitted parallel with the spindle by scraping the holes in the casting through which it passes. The outboard bearing or support *r* is fitted to the arm *h* and the hole *n* drilled and reamed by means of tools in the spindle. This insures the hole in the outboard bearing being in line with the spindle. The diagonal braces *s* for the arm and all other minor details are fitted as opportunity offers.

36. Erecting Trucks.—For erecting any machine, such as a milling machine, it is handy to have erecting trucks fitted to contain all the small parts of the machine. When an order for a number of machines is placed in a shop, many of the small parts are made and kept in stock. When the larger castings come on the floor and the work of erection begins, the man in charge of the erection takes to the stock room as many trucks as he has machines to erect, and puts the necessary stock for each machine on the trucks. These trucks are then placed opposite the castings for the machine with which they are to go. When this practice is followed much time will be saved, as the erector will always have the necessary parts at hand.

37. Inspection of Milling Machines.—The machine now goes to the inspector, who carefully tests all parts and motions for accuracy, testing the knee at the highest and lowest positions; also the clamp bed at its inner and outer positions and the table at both ends of its travel. A carefully ground steel testing bar, one end of which is ground to fit the tapered center hole of the spindle, is placed in the spindle, care being taken to see that both the hole and the test bar are clean before it is introduced. The parallel part of the bar projects from the spindle to the outer end of the knee.

No..... Universal Milling Machine.

Lot..... **Construction No**..... **Serial No**.....

Spindle runs at mouth,.....; end,.....
" with knee in Ver.....; Hor.....
" " frame in drop,.....; width,.....
" " overhanging arm,.....in.....inches.
" " center in O. H. arm, high.....; low.....
" " bushing in O. H. arm, high.....; low.....
" " surface of platen, length.....; width.....
Slot with ways of platen,.....
Spiral Head Spindle runs at mouth,.....; end,.....
" " " with slot,.....
" " " " center of slot,.....
" " " " back center in Hor.....;Ver.....
" " " " platen when at 90°,.....
" " " " main spindle when at 90°,.....
Eccentricity of swivel bed with main spindle,.....
Collet runs at mouth,.....; end,.....
Chuck runs out on { Main Spindle,..... / Spiral Head Spindle,.....
Vise out of parallel with platen in its width,.....
Back gears run,.....

Passed,.....190...by.....
BROWN & SHARPE MFG. CO. *Inspector.*

REMARKS:

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.....
.....

The spindle and the test bar are then revolved, and the amount that the test bar runs out of true both at the spindle and at the outer end is carefully noted by means of an indicator reading to thousandths of an inch. The test bar may also be used for measuring, by means of an indicator, to see that both ends of the table are the same distance from the spindle. The inspector is given a list of the allowable variations in the different parts of the machine, and he must not pass a machine until all errors have been corrected so that the variation shall not exceed the allowable limit. In the case of a universal milling machine, the universal head and tail-stock center are also tested. In testing the universal head, a test bar similar to the one used in testing the spindle is employed, in order to determine whether or not the spindle of the universal or spiral head runs true. The vise and chuck are also tested to see whether or not they are true.

38. Inspector's Report.—All information obtained from the inspection should be entered on a report similar to the accompanying one. Each machine is given a serial number, and these reports are filed at the office, so that in the case of any trouble arising or any repairs being required for a given machine, an exact record of its condition when it left the shop is available.

ENGINE ERECTION.

39. Equipment Necessary.—The manner of erecting an engine depends both on the equipment at hand and the style of the engine. Where medium-sized or heavy engines are to be erected, traveling cranes should be provided for handling the heavy parts, as they can accomplish the work much more quickly and easily than any other system of handling device. Another advantage of the traveling-crane system is that the traveling crane commands the entire erecting floor. The crane should have sufficient height of lift to place in position the highest parts of any machine built in the shop. Where very high work is to be erected, it is sometimes necessary to set the base in a pit so

that the highest parts will not come above the crane. This is especially true in erecting vertical engines. Some shops making a specialty of vertical engines have two sets of traveling cranes, one above the other, the lower one intended for handling the heavier pieces and the upper one for handling the upper portion of the engine and the light pieces. If an engine should be so high as to interfere with the travel of the lower cranes, it will be necessary to see that there is a crane set on each side of the engine before cylinders are put up, so as not to cut off the rest of the erecting floor from the crane service during the time that the high engine is in the shop. One advantage of having light quick-motion traveling cranes placed well above the heavier cranes is that the upper cranes can take light pieces and lift them above the lower cranes and carry them to any place on the erecting floor without interfering with the heavy work of the larger cranes.

All floors on which erecting is done should be firm and solid, so that there is no danger of the work being thrown out of line by settling when heavy parts are added. Before beginning work, the erecting floor should be cleared of all unnecessary obstructions and swept. The influence of the style of engine on the manner of erection will be brought out in the description of the three principal types of horizontal, vertical, and locomotive engines. For the erection of small engines an iron-plate erecting floor on which the engine can be bolted down and tested is a great convenience.

ERECTION OF A HORIZONTAL STATIONARY ENGINE.

40. Preparation of the Engine Bed.—Before the engine bed is brought to the erecting floor it should be machined as far as possible, including the boring of the main bearing, if this is cast with the bed, and the scraping of the guides. The guides are usually scraped to a special surface plate, or in some cases to the crosshead itself, before the

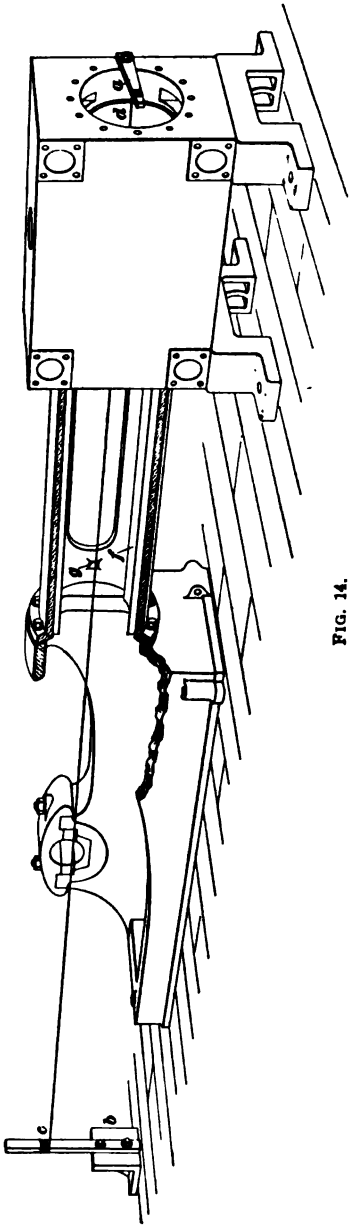


FIG. 14.

work is brought to the erecting floor. The method of erecting a horizontal engine is not influenced greatly by the type of engine; that is, the work of erecting both Corliss and slide-valve engines is very similar. It is best to carefully level up the bed on the erecting floor. This may be done by placing levels on the guides and in the pillow-block bearings.

41. Fitting the Main Bearing and Cylinder to the Bed.—In case the main bearing is cast separately from the bed and attached by bolts, it is necessary to bring it approximately square with the bed. This may be accomplished by placing a line through the crosshead guides and another one through the pillow-block and testing them to see that they are at right angles. This method will only set the bearing approximately square with the bed, though it will usually set it so nearly square that any further adjustment can be made by scraping the shaft bearing. The bed with the pillow-block attached should be carefully leveled by means of leveling jacks or wedges.

The cylinder is bolted to the bed or frame and a line or wire fastened to a piece of wood bolted to one of the studs in the end of the cylinder, as shown at *a*, Fig. 14. This line is carried through the cylinder, piston-rod stuffingbox, and guides, and fastened to the end of the frame in case the pillow-block is cast solid with the frame; or in the case of an engine in which the pillow-block is bolted to the frame, the line may be fastened to any suitable object, as, for instance, the angle plate and stick shown at *b*, Fig. 14. The line should be set central with the bore of the cylinder at the back end by calipering from the inside of the cylinder to the line. This may be done with an inside adjustable gauge or micrometer, but in most cases it is better to use a light pine stick like that shown in Fig. 15. The stick *a*



FIG. 15.

is tapered at both ends and may have a pin *b* driven in at each end. The advantages of the stick in calipering are that it is lighter than the inside micrometer and is not affected by expansion and contraction as much as a metal gauge would be.

The line must also be brought central with the stuffingbox at the other end of the cylinder. This may be done by means of a stick similar to that shown in Fig. 15, but it may be done more quickly by means of the device shown in Fig. 16. This consists of a hard-wood block *a*, which is turned to just fit the stuffingbox and has a $\frac{1}{4}$-inch hole *b* drilled in the center. The face of the block is turned square with the outside, and two center lines *c d* and *e f* are drawn across the face at right angles to each other. By sighting along the lines *c d* and *e f*, it is easy to determine when the line or wire *c d*, Fig. 14, is central with the stuffingbox.

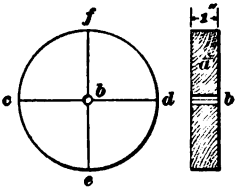


FIG. 16.

42. Lining the Guides to the Cylinder. — After this the guides may be lined to the cylinder by measuring from the inside of the guides to the line at the top and bottom, as at *f*, Figs. 14 and 16, which will determine whether the line is central to the guides in a vertical plane. This test should be made at each end of the guides. In order to see whether or not the line is central horizontally, spots *g*, Fig. 14, are cast on the frame and faced off by the boring tool at the same time that the guides are bored.

Another and quicker method of lining the guides with the cylinder is to use special devices similar to that illustrated in Fig. 17. This consists of a casting *a* that is turned to fit

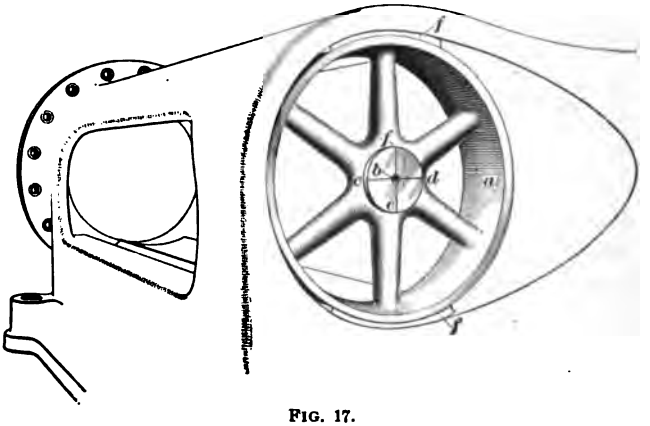


FIG. 17.

the inside of the guides. At the center there is a small hole *b* through which the line passes, and the lines *c d* and *e f* drawn at right angles to each other serve to locate the center line in its proper position, this being done in a manner similar to that described in Art. **41.** When the device shown in Fig. 17 is used, the spotting plates *g*, Fig. 14, are not necessary.

43. Bringing the Cylinder in Line With the Guides.—If it is found that the cylinder is not in line with the guides, it is necessary to fit the joint between the cylinder and guides so as to bring them in line. The amount of

adjustment necessary may be determined by slacking off the nuts on one side and introducing pieces of sheet metal until the cylinder and guides are brought into exact alinement. After this an amount equal to the thickness of the metal introduced may be removed from the other side of the end of the cylinder or guides. Where this amount is very small, it is sometimes removed by filing or scraping; when it is greater, by machining.

It has been found practically impossible to machine parts so accurately that the cylinder of a large engine can be brought in line with the guides without fitting, and on this account many manufacturers place a loose ring or spacing piece between the cylinder and the guides, and in the case of a tandem compound engine, between the high-pressure and low-pressure cylinders. After the amount of adjustment necessary has been determined, this distance piece is taken out and the proper amount removed from the high side. When this method is followed, care must be taken to mark the distance piece so that it cannot be placed in a wrong position. To insure this, it is well to have at least one of the stud or bolt holes uniting the parts not located according to the regular spacing system, so that it will be impossible to put the castings together in any but the correct position. This may also be accomplished by using guides or dowel-pins.

Many engine builders bore all their cylinders and guides in a vertical boring mill and so reduce the difficulty of fitting the parts, but in the case of a horizontal engine, the parts will spring out of round when placed in a horizontal position.

44. Fitting the Crank-Shaft.—After the cylinder and guides have been brought into perfect alinement, the crank-shaft must be fitted. The outboard bearing may be located by stretching a line through the shaft bearings at right angles to the lines through the cylinder and guides. This will serve to locate the outboard bearing very closely. After this has been done, the journals of the shaft should be wiped clean and given a coat of marking material. The

shaft should then be placed in its bearings with the lower half of the boxes in position and given a few revolutions. The shaft is then lifted out of the bearings and the high spots scraped off with a half-round scraper. This operation is repeated until the shaft shows a good bearing in both the main pillow-block and the outboard bearing. After the lower half of each box is scraped, the upper halves may be put in place and fitted in like manner. The shaft is then taken from the bearings and the cranks pressed or shrunk on and keyed. The eccentrics and governor-driving device are also placed in position, after which the shaft is returned to its place.

In order to make sure that the crank-shaft is exactly at right angles to the center line of the engine, and that it is

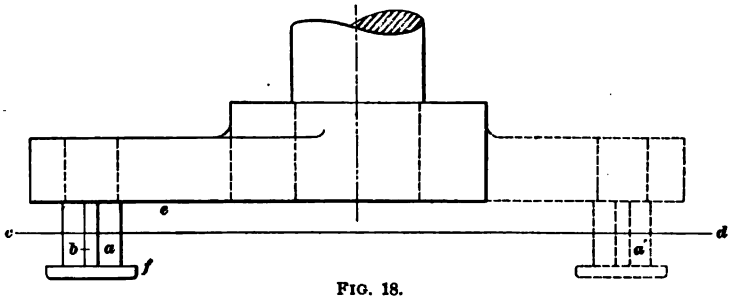


FIG. 18.

also horizontal, the following course may be pursued: The crankpin *a*, Fig. 18, is brought up to the center line *c d* of the engine and a piece of wood *b* is fitted between the face of the crank *e* and the head of the crankpin *f*. A mark is made on this piece of wood in the middle, and this mark should coincide with the line *c d*. If they do not coincide, the outer end must be moved until they do. The shaft is now given a half revolution to bring the crankpin under the line at the other end of its travel, as shown by the dotted lines at *a'*. If the line on the stick *b* again coincides with the center line *c d*, the shaft is at right angles to the center line of the engine. In order to test the shaft to see whether it is level or not, a fine plumb-line may be hung

vertically before the shaft and the crankpin *a* brought in contact with it at the upper portion of its revolution, and then tested again at the bottom of the revolution. If the crankpin just touches the line at both the top and the bottom, the shaft is horizontal.

45. Fitting the Reciprocating Parts.—After the engine is lined up and the shaft square and level, the reciprocating parts may be put in place. The piston, with its piston rod attached, is slipped into the cylinder and the crosshead into the end of the guides. The piston rod passes through the bushing in the head of the cylinder and is secured to the crosshead. These parts should be tested as they are put in place, to see that they line up properly. Some makers use a crosshead of such a pattern that the line *c d*, Fig. 14, may be carried through the crosshead and used in testing the crosshead to see that it lines up properly. After the crosshead and piston rod are in place, the connecting-rod may be put on. Before any of the surfaces that are to slide or move on one another are placed in contact, care should be taken to see that they are well oiled. The oiling devices are put in place as fast as the parts are ready for them.

The control of the movements of the engine depends on the governor; consequently, great care should be taken to see that there is no danger whatever of the governor sticking or failing to act. In order to insure this, the governor should be assembled separately and belted up so as to run at about its normal speed. The gears should be fitted so as to run as quietly and as smoothly as possible, and the dashpots, weights, and all parts properly adjusted during this preliminary run. It is usually best to run the governor one or two days in this way. After the governor has been fully adjusted, it may be taken down and placed on the engine. If the engine is a Corliss engine, the dashpots are responsible for the closing of the valves, and hence they should be assembled and tested before being placed on the engine. Shops building this class of engines usually have some

device in which they can place a dashpot and run it for some time while adjusting it. After the dashpots are fully adjusted they are placed on the engine.

46. Oiling Devices and Other Small Parts.—The oiling devices for the crankpin, eccentrics, crosshead, governor, and all other parts are put in place as fast as the parts are ready to receive them and they should all be tested before steam is let into the engine.

47. Fitting the Flywheel.—Flywheels for small engines are made either solid or in halves. If the flywheel is made solid, it must be placed on the crank-shaft before this is lowered into the bearings. In some cases there is not room in the shop to put the flywheel in position, and hence the engine is assembled without the flywheel being placed on the shaft. Where it is possible, it is best to erect the flywheel with the engine. In erecting a large built-up flywheel, the hubs and hub flanges are placed on the shaft first. The arms and segments of the rim are then attached one at a time. By beginning the work on one side, the arms and sections of the rim may be attached to the hub flanges near the floor level, thus doing away with the necessity of raising them to any great height. After one arm and section of the rim are put in place, they may be lowered into the pit and the next one in order connected. This process may be continued until the wheel is completed. When the work is done under a traveling crane, it is usually more convenient to place each of the arms and segments at the top of the wheel and then lower them far enough to make room for the next.

48. Use of Dowel-Pins.—Whenever it is necessary to make the bed of an engine in sections, or whenever there are any parts that require accurate alinement, they should be doweled together This is done by drilling holes through the pieces and reaming them out with a taper reamer after the work is erected. After the holes are drilled and reamed, taper pins are fitted to them. These pins are usually given a taper of from $\frac{3}{8}$ to $\frac{3}{4}$ inch per foot. As each part is put in place, it should be clearly and distinctly marked by

letters, figures, and lines, so that it may be easily returned to its position when erecting in the field. If the work is complicated, it is well to keep a record of the marks used so as to avoid confusion in the final erecting.

49. Lagging.—When the cylinder attachments have all been put in place and the cylinder tested, the jacket or lagging is put on. This, in the case of small engines, may consist simply of a sheet of Russian iron cut to the proper form, bent, and screwed to the flanges of the cylinder. In the case of large engines, a framework of flat or angle iron is fitted to the cylinder and wooden strips or sheet-steel lagging fitted to this framework. If the lagging is composed of iron or steel, it is put in place by a machinist, while if it is made of wood, a carpenter or patternmaker is called on to do the fitting.

50. Placing the Engine on Dead Center.—It is often necessary to place the crank on the dead center when setting the valve, and this is done in the following manner: The crank is turned so that the connecting-rod will stand

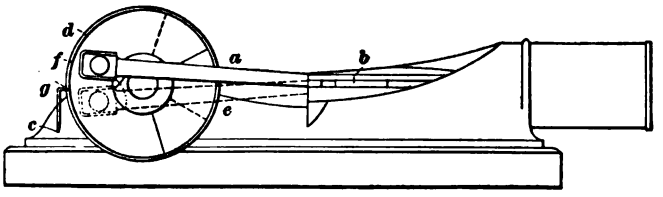


FIG. 19.

in the position shown by the full lines *a*, Fig. 19, and a line *b* is drawn on the crosshead and guide. A scriber or tram similar to that shown in Fig. 20 should be placed in a prick mark *c* on the bed, and a line *g* drawn on the crank. The crank should now be rotated so as to bring the rod into the position shown by the dotted lines *c*, and when the lines *b* on the crosshead and guide coincide, another line *d* is drawn on the crank. The distance from *g* to *d* may be bisected with

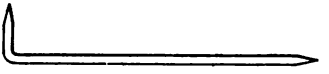


FIG. 20.

a pair of dividers, which will give the line *f* on the crank, and when this line is set to the tram, the engine is on the dead center. This operation may be repeated when it is desirable to get the dead center on the other end. If the crank is of such form that it is not convenient to use it in this manner, the flywheel may be used instead.

51. Valve Setting.—No definite rule can be given for setting the valves of steam engines, as the work is largely a matter of judgment. The valves and valve gear are designed in the drawing room, and the details are worked out in the machine shop according to the drawings, which, in the case of complicated valve gears, give full directions for setting them. The slide valve is the one most commonly met, and a description of the manner of setting this will be given.

As a valve gear is generally constructed, there are two ways of adjustment provided. The first consists of a change in the length of the valve stem and the second consists in rotating the eccentric on the shaft. By altering the length of the valve stem, the valve may be made to travel equally each way from mid-position; that is, if the valve travels $\frac{1}{2}$ inch too far toward the head end, shortening the stem half that amount pulls the valve $\frac{1}{4}$ inch nearer the crank and makes it travel equal each way, and any movement of the eccentric hastens or retards the valve action as it may be moved ahead or back.

The valve must be made to move centrally by adjusting the valve stem and at the right time, by moving the eccentric. To accomplish this, set the crank on one of the dead points and set the eccentric so as to give as nearly the proper angle of advance as can be judged. The lead may now be measured and the crank set on the other dead point and another measurement of the lead made. The valve may now be moved half the difference of the two leads and be given the correct lead by moving the eccentric, which should bring the lead the same at each end. No general method can be given for the detailed setting of all forms of valves, as this depends largely on the design.

52. Painting and Finishing.—All rough places on the bed are smoothed off by chipping and filing before painting, or in some cases the bed is given a coating of filling material that fills all depressions. After the bed has been filled and rubbed down with sandstone or sandpaper, it is painted. In some cases the specifications call for the testing and acceptance of the engine before painting.

53. Dismantling the Engine.—When the work is passed or pronounced correct by the superintendent or inspector, the man that has had charge of the erection of the engine oversees the taking down and prepares the parts for shipment. The lagging is usually removed and boxed. All small parts are also boxed. These boxes should be numbered and a careful record kept of their contents. The cylinder, in the case of large engines, is mounted on skids. In some cases the cylinder is covered with non-conducting material, so as to prevent the radiation of heat when the lagging is in place. This non-conducting covering may be applied in the shop previous to shipment, or may be applied in the field. All finished parts of the work are given a coating of some protective material that will prevent rusting. The bearings or fitted surfaces are boxed or covered with boards to protect them from injury. Crankpins and main shafts are sometimes wrapped with burlap or rope, and if large and finely finished, they may be lagged with wooden strips. In the case of comparatively small engines, the entire engine is sometimes placed on skids. In case the machinery is to be shipped by rail, care should be taken to see that the heavy parts of the load come over the trucks, the lighter parts, boxes, etc. being located near the center of the car. All parts should be securely fastened, so that they cannot shift during shipment.

54. Foundation-Bolt Templet.—While the engine is being erected in the shop, a templet for locating the anchor bolts in the foundation is made. This templet should include the correct location of all bolts for securing the engine bed, cylinders, and outboard bearing to the

foundation, and in the case of a large and complicated plant like a hoisting engine, should also include the bolts for the steam brake, steam reverse, drum-shaft bearings, etc. The templet is usually laid out from the drawing, after which all the dimensions should be checked by actual measurements of castings, in order to see that there is no discrepancy between the drawing and the casting. After the holes have

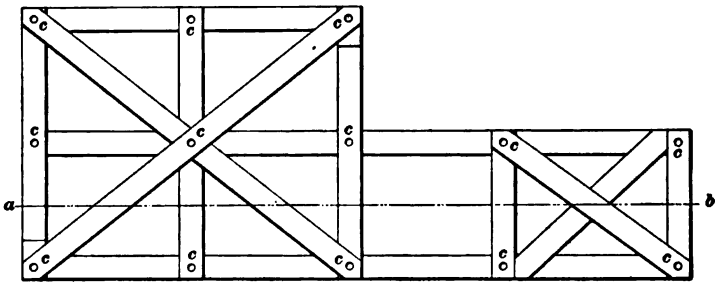


FIG. 21.

been properly laid out, they are bored the same size as the anchor bolts. This templet is usually made of 1-inch white-pine lumber and must be thoroughly braced. The parts should be put together in a substantial manner with screws or bolts, or both, and also marked so that after being taken apart for packing and shipment, the templet can be easily and accurately assembled at the foundation pit. Fig. 21 shows a plan of such a templet.

ERECTION OF ENGINE ON FOUNDATION.

55. Foundations.—The foundations may be composed of masonry, brick, or concrete. Stone and brick should be laid in good cement mortar. The bolts may be built into the foundation or pockets may be left at the bottom for the washers and nuts, and holes left for introducing the bolts later. In some cases, these holes may be made by building wooden boxes or iron pipe into the foundation. In still other cases, the foundations are built with pockets near the

bottom, and then the masonry or concrete built up solid, after which the bolt holes are drilled with a diamond drill. When the foundation is made of concrete, it is usually better to build the bolts into the foundation. In small work a bunch of burlap may be wrapped around each bolt and these bunches are then raised along the bolts as the brickwork or masonry progresses, thus leaving clearance spaces around the bolts.

The anchor bolts may be held down in a variety of ways. Sometimes a large washer is placed on the lower end of each bolt. In other cases a stirrup is formed at the lower ends of the bolts and pieces of railroad iron passed through these, as shown at *a*, Fig. 22. The pieces of iron may be long enough to extend through the stirrups of two or more bolts at once. The foundation-bolt templet *b*, Fig. 22, is

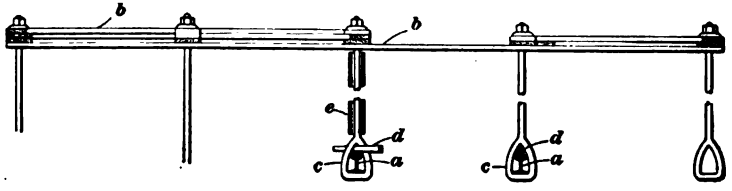


FIG. 22.

supported on suitable blocking in a level position and rigidly braced to support the bolts. Sometimes it is necessary and best to suspend the templet by braces from overhead supports. The rails *a* should be wedged against the bottom of the stirrups *c* by driving wedges on top, as shown at *d*. In order to allow some adjustment of the bolts, a piece of pipe may be placed about them, as shown at *e*.

56. Appliances for Erecting the Engine on the Foundation.—The engine is sometimes erected on the foundation by the same man that did the erecting in the shop. In the shop, the erector has the advantage of all the shop tools and appliances, including cranes, special tools, etc. When the engine is shipped from the works, the man that is to go with it selects such tools as he requires. The

tools needed vary greatly with the work and with the locality in which the engine is to be erected. Most modern power houses have traveling cranes in the engine rooms that can be used in erecting the engine or for any future repair work. In this case very few tools will be required. If the engine is to go into a region a long distance from any shop, as, for instance, a mining camp, the erector must take practically everything with him that he will require. Usually one or two hydraulic or stone jacks, a few screw jacks, and some pinch bars will be all of the larger tools necessary, and, in addition to this, a liberal stock of heavy ropes, wrenches, hammers, chisels, and other tools that may be necessary should be taken. All the small tools, together with supplies, waste, oil, etc., should be kept in locked tool chests. In case heavy parts have to be hoisted some distance, it may be necessary to take a chain block or a hand windlass, crab, or winch, to be used in connection with a block and tackle. Sometimes it is convenient to take a stock of rollers and blocking, but usually these can be obtained in the field.

57. Setting Engine on Foundation.—The engine bed and cylinder are placed on the foundation and bolted together. All the dowel-pins are fitted and the engine is lined up by stretching a line through the cylinder and beyond the crank, just as was done in the shop. The engine can be supported on iron wedges during this operation. The outboard bearing can be put in place and squared by means of the crank, as described in Art. **44.** After the bedplate is properly located over the anchor bolts, the clearance spaces left around the bolts in the masonry should be filled with cement. This is mixed the same as that used under the engine bed, as noted below. Enough water is added to the cement mixture so that it will flow readily into the holes. In large work with removable bolts, the cementing is not required. After the engine has been bolted together and lined up, the space between the bottom of the bedplate and the foundation may be filled with some suitable compound. In some cases melted sulphur is used, in others a

mixture of iron chips and sal ammoniac is rammed in with a calking chisel, while in still other cases Portland cement mixed in a proportion of 1 part cement to 2 parts sand is employed. When the cement has hardened, the flywheel or pulley may be put in place and the caps over the bearings adjusted. All parts that are subjected to friction should be thoroughly oiled before being put into place, as an unoiled surface sometimes cuts during the first few revolutions before the oil reaches it through the oil hole. The piston, cross-head, connecting-rod, cylinder head, governor, valve gear, oiling devices, lagging, and piping are assembled in the order named.

The engine may now be turned a full revolution by hand to make sure that all is clear. Next, care should be taken to see that everything is in adjustment; then the steam may be turned on and the engine started very slowly. After the engine is started with steam, a thorough inspection of all working parts should be made and all the oiling devices properly adjusted. Any parts that have been left too loose may now be tightened to proper running fits, and any part that shows a tendency to heat should be examined and adjusted. After the engine has been running at full speed for some time, it may be belted up and kept at work while the indicator test is being made. This test will usually show any defect in adjustment of valve setting, which may be corrected at this time.

ERECTING A VERTICAL STATIONARY ENGINE.

58. General Consideration.—The method followed in erecting a vertical engine does not differ materially from that used in the horizontal engine, but as the parts are differently arranged, and in most cases some additional parts are required, a description showing the principal points of difference may be of interest. As a rule, it is more difficult to erect a vertical engine without the aid of cranes or hoists than a horizontal engine. Very large horizontal engines are frequently erected in the field without

any hoisting tackle whatever, all the parts being moved on rollers and lined up by means of jack-screws. In the case of a vertical engine, it is usually necessary to rig a derrick, shear legs, or some hoist when in the field.

59. Work Necessary on the Bed.—The bed *a*, Fig. 23, is leveled by means of wedges or erecting jacks, as in the case of a horizontal engine. The bearings for the crank-shaft may be scraped either before or after the guides

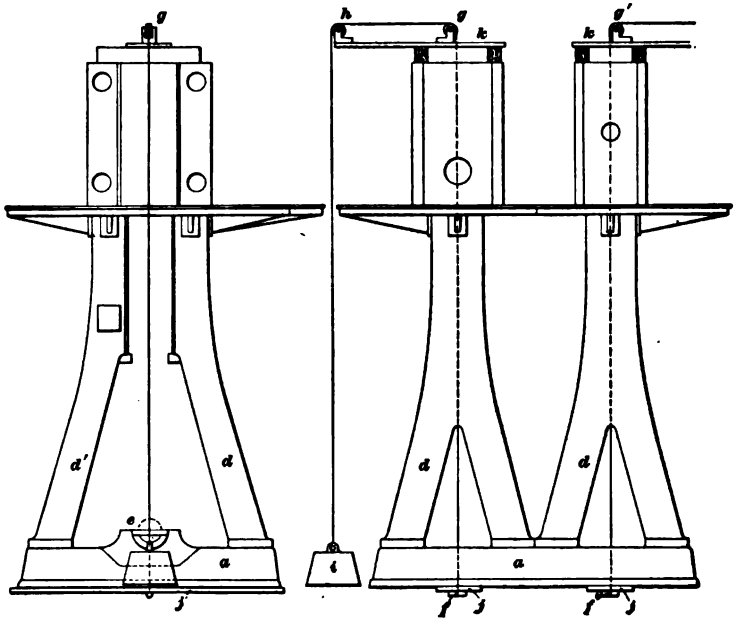


FIG. 23.

are in place. Sometimes, to aid in scraping these bearings, a hollow cast-iron shaft is made of the same diameter as the crank-shaft. This is lighter than the crank-shaft and serves as a surface plate for scraping the bearings into line.

60. Fitting the Guides and Cylinders.—The frames and guides *d* and *d'* are placed on the bed and temporarily bolted down. A center line along the center of the shaft is

established by placing blocks across the bearings, as shown at *e*. A piece of tin is fastened to the center of each one of these and a center line marked on it. A long straightedge is then laid across both blocks and a center line established. A line, as *f g h i*, is stretched through each cylinder. The line is secured at the bottom to a plank *j*, which is blocked or clamped to the bottom of the bedplate and has a hole in the center through which the line passes. At the upper end, above the cylinders, the line is secured to the plank *k*. The line passes over pulleys at *g* and *h*, and is kept taut by a heavy weight at *i*; a piano wire capable of standing a breaking stress of 400 pounds is usually used for this purpose, and the weight at *i* may vary from 100 to 200 pounds. This weight should be located so that it will do no damage if the wire should break. After the line is established, the guides and cylinders are adjusted to it. If desired, the weight at *i* may be hung under the cylinders in place of the plank *f*. It is best to suspend the weight in a vessel of water to prevent vibration. Great care must be taken to see that the lines *f g* and *f' g'* are the same distance apart, both top and bottom, and are in the same vertical plane.

If it is found that the cylinder does not come in line with the guides, packing pieces must be placed between the cylinder and the guides, as in the case of a horizontal engine, after which a sufficient amount must be dressed from the end of the cylinder or the intermediate piece, bringing the two into alinement. In measuring from the line to the cylinders, or from the line to the guides, a wooden measuring piece may be used, as described in Art. **41.** After the cylinders and guides are properly located, they are securely clamped in place, and the bolt holes for holding the uprights to the bed, the guides to the uprights, if the latter are made separate, and the cylinders to the guides, are reamed ready for the bolts, and the holes for the dowel-pins are drilled and reamed and the pins fitted.

61. Placing Reciprocating Parts.—The placing of the reciprocating parts of vertical engines does not differ

materially from that of horizontal engines, and the method of squaring the crank-shaft to the center line that is used in the horizontal engine can also be employed in the vertical engine.

62. Oiling Devices and Smaller Parts.—In some cases, vertical engines are fitted with separate oiling devices for each bearing, while in other cases an oil tank is arranged at or near the cylinder from which pipes lead to the various bearings. Another system provides a reservoir with a pump, either attached to the engine or as a separate machine, which distributes the oil through a suitable arrangement of piping. All these devices are placed in position during erection. Owing to the fact that many parts of the engine are not accessible from the floor, it becomes necessary to provide some device by means of which the attendant can reach any part of the engine. To accomplish this, platforms or floors are built around the engine at different elevations. These platforms are usually iron plates supported on brackets, and are reached by staircases leading from the floor of the engine room. These brackets and plates are all placed in position as the various parts of the engine are being assembled. In the outer edge of the plates, provision is made for standards, which carry a hand rail, usually composed of a piece of brass or iron pipe. Large vertical engines are often provided with hand or similar turning gear for turning the engine around a portion of a revolution in starting or when fitting belts. They are also supplied with steam, vacuum, and revolution gauges, and a clock. Provision must be made for attaching these to the engine frame, though they are not generally assembled in place until the engine is erected upon its foundation; or they may be erected on a board entirely separate from the engine. Provision must also be made on all engines for attaching the steam indicator.

63. Dismantling Vertical Engines. — After an engine has been erected and tested, it is dismantled in a

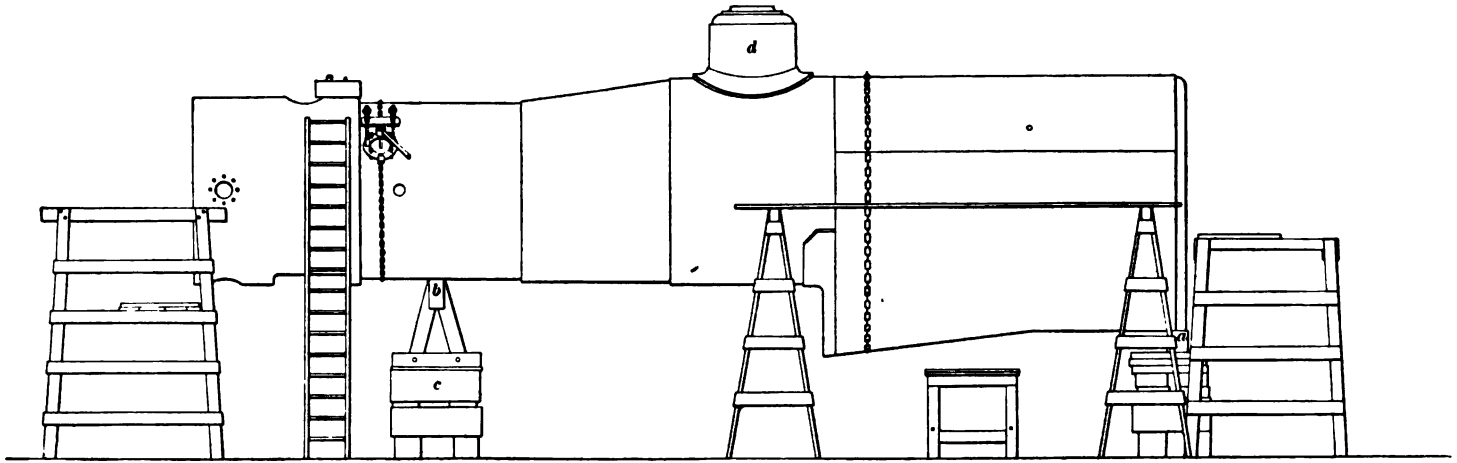


FIG. 24.

manner similar to that used in taking down large horizontal engines, except that it must be done to a greater extent.

64. Erecting on Foundation. — The erection of a vertical engine on the foundation does not differ materially from that of a horizontal engine, with the exception of the fact that in some cases a line is not stretched through the engine when it is erected on the foundation. When no line is used, bolts and dowel-pins are depended on entirely for bringing the parts into line. Care must be taken in erecting a vertical engine to see that the bedplate is carefully leveled and has a firm bearing before the other heavy parts are assembled on it.

LOCOMOTIVE ERECTION.

METHOD BY PLACING THE BOILER FIRST.

65. Methods of Erection.—The erection of locomotives varies in different shops, not only owing to the different ideas possessed by the men in charge, but also on account of the varying equipment of the shops. In one method the locomotive boiler is placed first and all the parts assembled about it, the principal argument in favor of this method being that the boiler is the stiffest thing about a locomotive engine, and hence everything should be lined up to fit it. In the other method, the frames and working parts are erected first and the boiler placed on them. The first method will be now considered.

66. Placing the Boiler. — In Fig. 24, a locomotive boiler is shown ready for assembling the other parts about it. The length of the top part of the blocking at *a* under the firebox end must be less than the distance between the two frames, so as not to interfere with the other placing. The barrel or shell of the boiler is supported by a strong trestle *b* that rests on the block *c*. It is not necessary that the boiler be level endwise, but care should be taken to have

it plumb sidewise. The center of the dome *d* should come over the center line of the bottom of the firebox, and each side of the barrel of the boiler should be equally distant from the vertical center line. Should there be any slight discrepancies in the shape of the boiler, they should be averaged in the setting. In other words, in case it is found that with the center of the dome over the center of the bottom of the firebox the barrel of the boiler projects more on one side of the vertical line than on the other, the sides of the boiler may be brought equidistant, or nearly so, from the center of the bottom of the firebox, even if the dome is thrown slightly to one side.

67. Placing the Cylinders.—The cylinders are brought under the boiler and approximately to their places, the saddle *a*, Fig. 25, being in contact with the barrel of the boiler. Lines *b* and *b'* are then run through each cylinder and fastened to some fixed object, as the post *d* near the back of the firebox. The lines *b* and *b'* should be parallel and equidistant from the sides of the front end of the boiler shell, as shown by the line *c*, hung over the top of the boiler shell and having the weights *f* attached to each end. The two center lines are brought to the desired distance, plus the amount to be chipped off the saddle, below the firebox at the point *e*. This is accomplished by placing a straightedge under the firebox at *e* and measuring to the lines. The horizontal distance from the sides of the firebox to the center lines may also be determined and made equal on both sides. The erector then scribes a chipping line all around the saddle by means of a pair of dividers or a small surface gauge. The cylinders are next moved out in front of the boiler and the saddle chipped to the line referred to. The cylinders are then returned to their positions in contact with the boiler shell and tested by the lines. In some cases it may be necessary to remove them and make any slight corrections that may be required by further chipping and filing. A narrow chipping strip is provided all the way around the saddle *a* to facilitate this work of fitting.

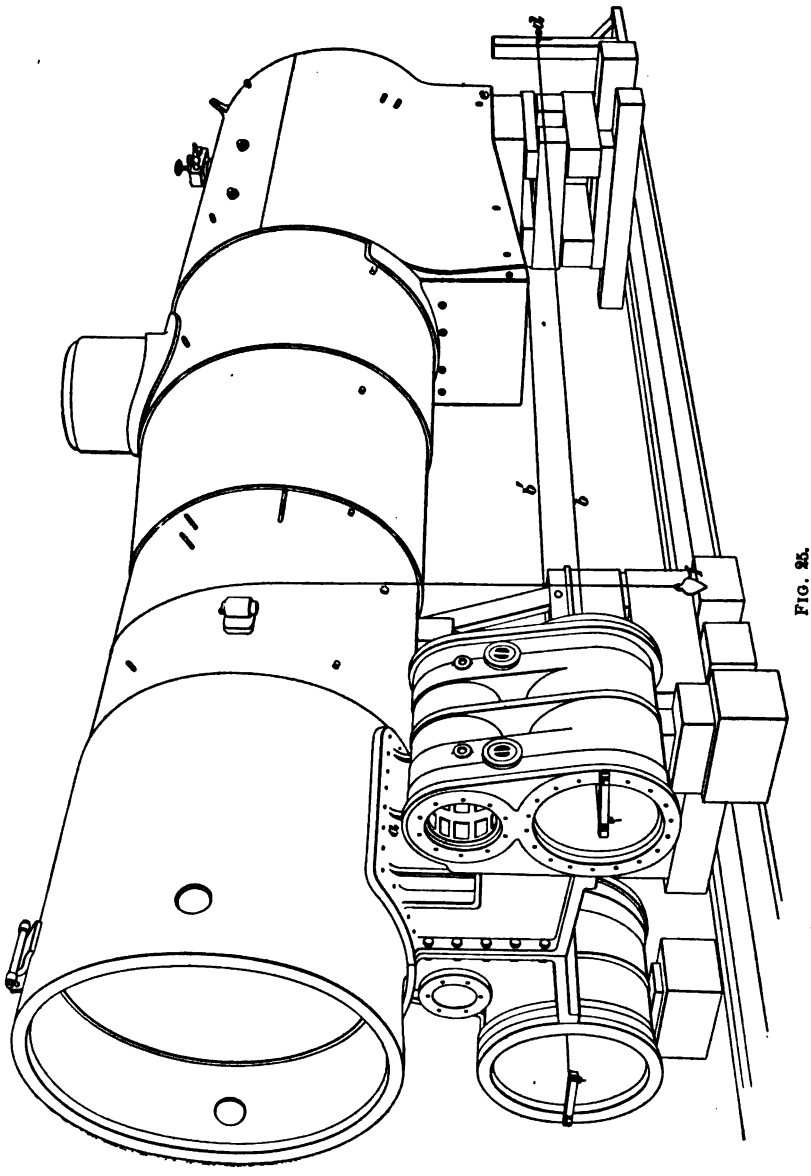


FIG. 25.

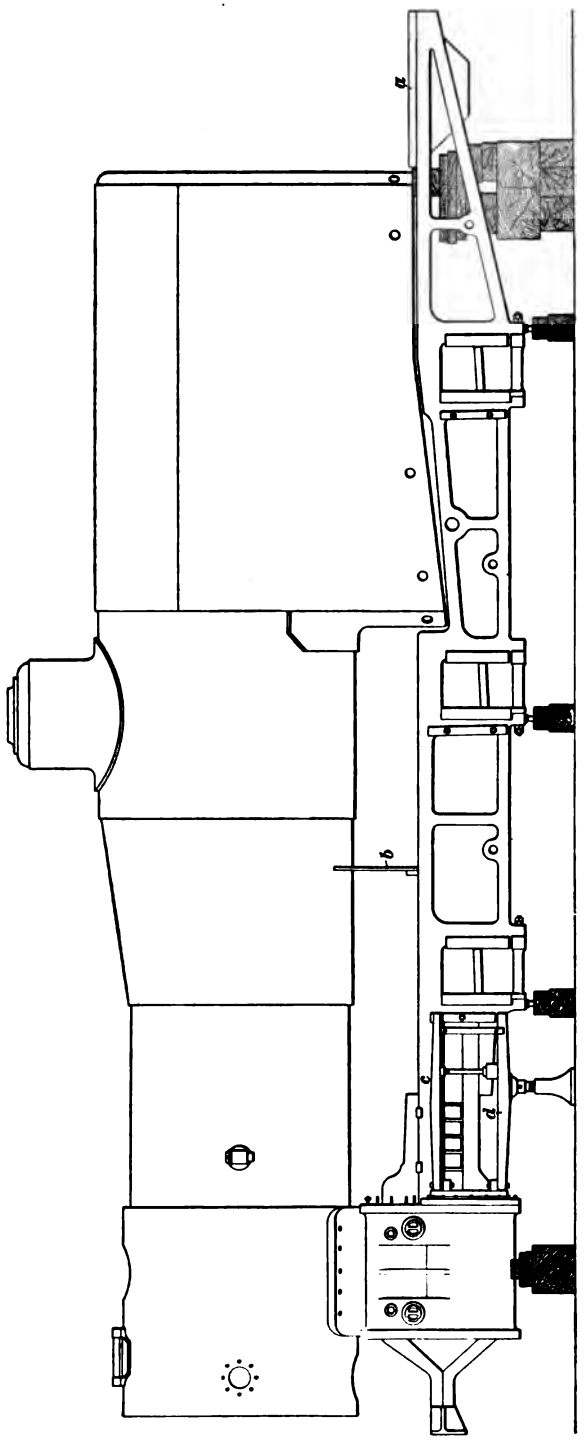


FIG. 26.

The space above the upper surface of the saddle *a* and between the chipping strips is then filled with cement to give a solid bearing between the saddle and the boiler. Different materials are used for this purpose, as, for instance, asbestos, stove putty, red and white lead cements with or without iron chips incorporated in them, and in some cases iron chips and sal ammoniac have been used to form a rust joint. In all cases considerable care is necessary to use just the right amount of material, on account of the fact that there is no chance to calk or drive it into place. After the space in the saddle has been filled, the cylinders are bolted to the shell and blocking placed under them to support the weight of the front end of the locomotive. The trestle *b*, Fig. 24, is then removed from under the barrel of the boiler, as it would be in the way during the latter operation.

68. Placing the Frames.—The frames are next placed in position, as shown in Fig. 26. They are bolted to the cylinders at the front end, and the foot-plate *a* is bolted across the back ends, which spaces them properly. The waste plate *b* is attached to the frames, but not to the barrel of the boiler. The guides *c* and *d* are bolted to the cylinders and blocked in place. In Fig. 26 the lower guide is supported by a jack-screw and the upper one by blocking. While this work has been in progress other men have put in the tubes and dry pipe, drilling and tapping the holes for the gauge cocks and cleaning plug holes, also the holes for the studs for the running-board brackets, sand box and bell, the combination globe or steam turret, and any other holes that may be required.

69. Lining the Guides.—The guides are supported at the back end by the yoke *a*, Fig. 27. A line *b* is passed through each cylinder to a piece of board held in one of the pedestals, as shown at *c*. These lines are centered in the front ends of the cylinders and in the piston-rod glands at the back ends. After the lines are in place, the guides are set parallel to the lines and the guide yoke adjusted. About this time the waste sheet *d*, Fig. 27, is secured to the barrel

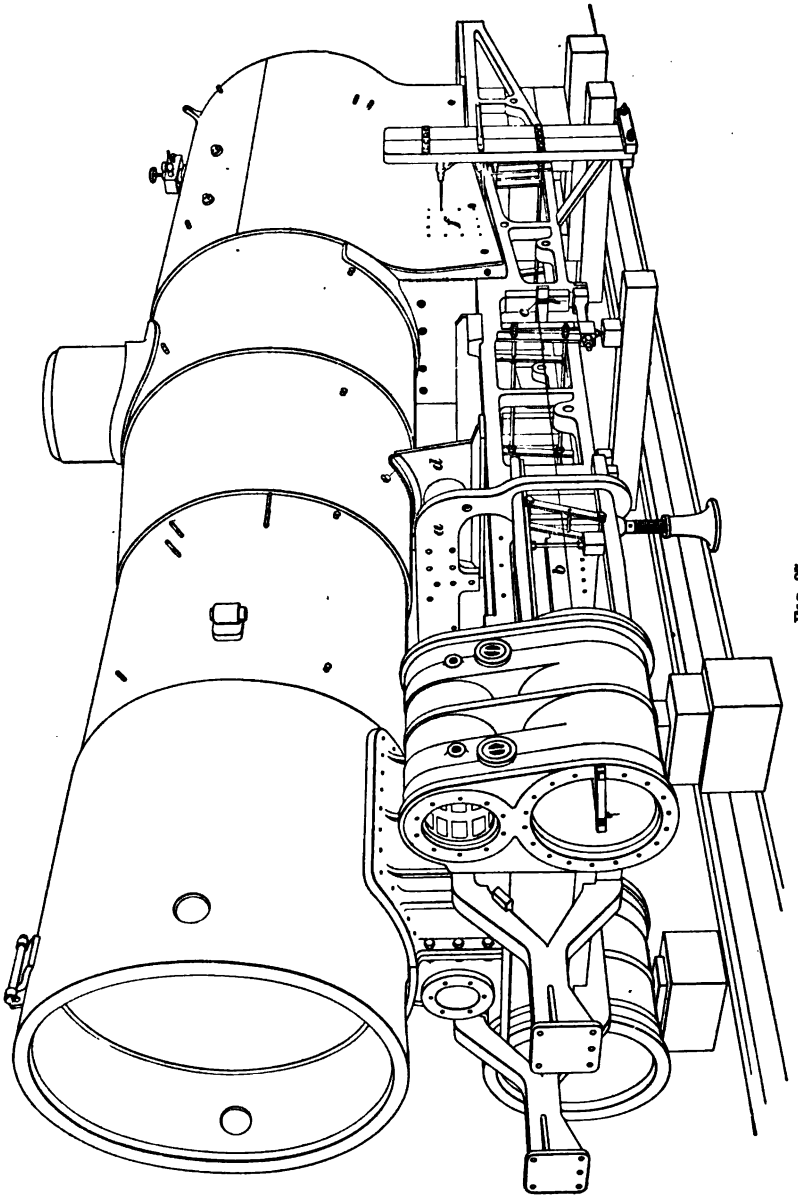


FIG. 27.

of the boiler by the angle *e*. After the guides and guide yoke are in place the yoke is secured to the frames by proper attachments and to the boiler by a sheet and angle, as shown at *a*, Fig. 28. While this work is going on the holes for the furnace pads (also called expansion pads or bearers) are drilled, as shown at *f*, Fig. 27, and the pads and links put on, as shown at *b* and *c*, Fig. 28. At the same time other men are placing other details, such as the bell, stack, oil pipes, etc.

70. Testing the Boiler.—The firing or testing of the boiler in some shops is done without taking the engine from the erecting floor. A better way is to run two temporary trucks, made expressly for the purpose, under the locomotive, as shown at *d* and *e*, Fig. 28. This enables it to be hauled to the transfer table and moved to the firing room. Locomotive boilers are sometimes tested by using steam piped to them from a high-pressure stationary boiler installed for this purpose, but the better practice is to use a fire in the firebox of the boiler, as this makes the test under actual working conditions.

The boiler is first filled to the top of the dome with hot water, through an injector. Any leaks that may appear are tightened by calking, and a water pressure sufficiently high is slowly applied. In ordinary practice this is about 240 pounds. While the pressure is on, if any leaks appear, they are marked with chalk. The pressure is then taken off, and the leaks that have been marked are carefully calked. The water is lowered to one gauge and a fire started in the firebox. The water will rise to two gauges by expansion. Steam is raised to the desired pressure, usually equal to the water pressure used. For instance, if the steam pressure were 240 pounds when this limit had been reached, the pressure would be reduced to 50 pounds, which process is repeated three times. The oil pipes are tested at the same time to see that they are all right before they are covered with the jackets. The jacket is not placed on the boiler until the engine is returned to the erecting shop after firing.

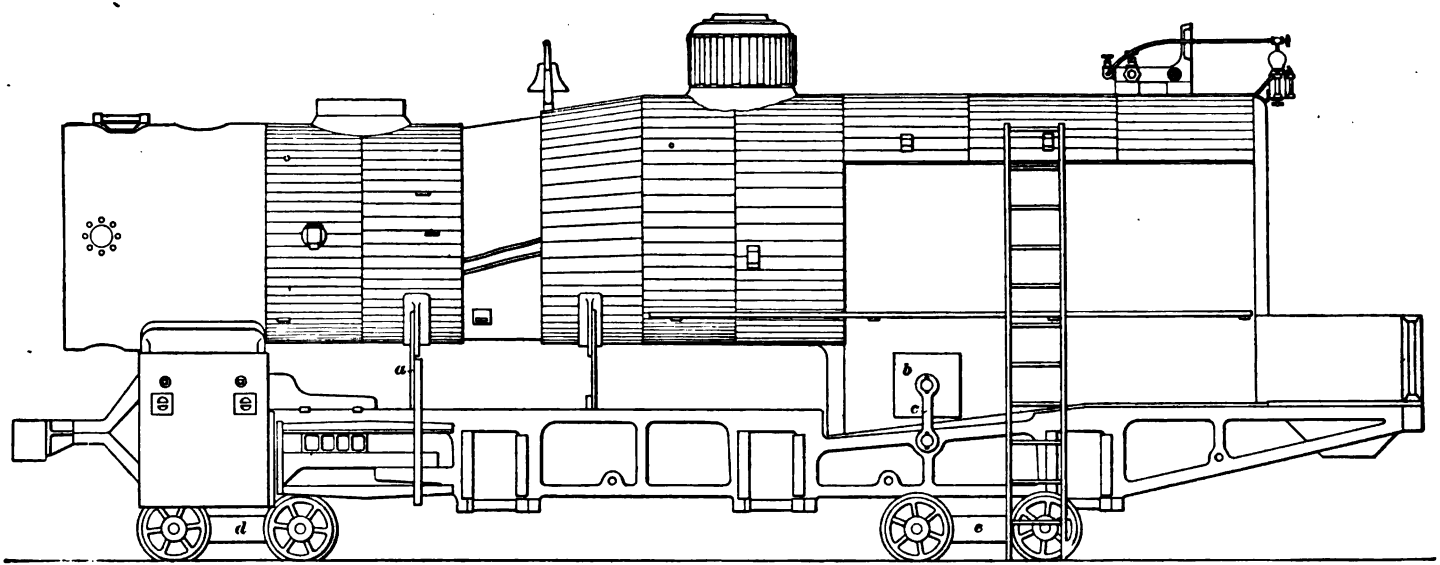


FIG. 28.

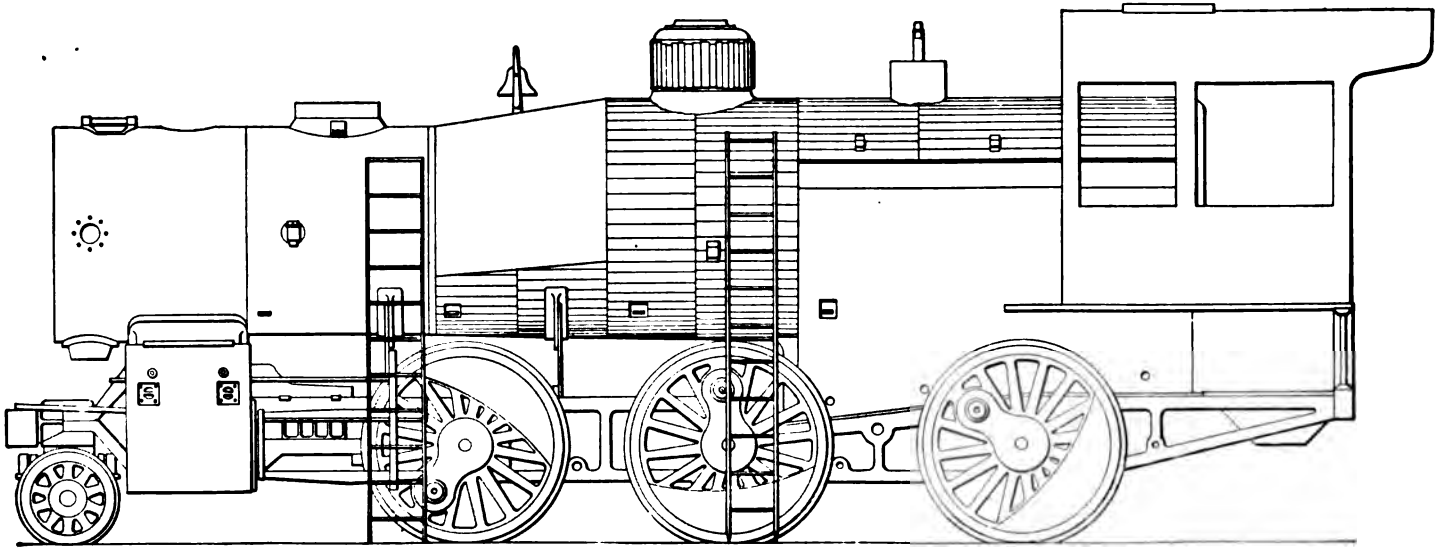


FIG. 29.

71. Placing the Wheels, Valve Gear, and Details. The locomotive is now brought back to the erecting shop and lifted from the temporary trucks by the traveling crane, and is ready for its own wheels to be run under it, including the truck. The engine is then lowered into place, as shown in Fig. 29. The links and motion work are next put up and the valves set. At the same time the boiler is being covered or lagged with a non-conducting material, and the planished iron jacket, running boards, cab, and pilot are placed in position. The running boards, cab, and pilot are made in a different shop and brought to the erecting floor ready for placing.

The painters have been following the machine work most of the time, as opportunity offers. The cab, sand box, and some other parts are painted before being brought to the erecting shop.

To enable men to work under the locomotive, an *erecting pit* about 38 feet long, 47 inches wide, and 32 inches deep is usually provided between the tracks of each erecting stall. This pit usually begins about 14 feet from the door.

The tender is made complete in another department, and is ready to be attached to the locomotive after it is run out from the erecting shop.

METHOD OF ERECTING BY PLACING THE CYLINDERS AND FRAME FIRST.

72. Placing the Cylinders and Frame.—In this method the cylinders are first placed on four jack-screws, the saddle having been machined to the same radius as the smokebox. The frames, guides and guide yokes, foot-plate, buffer beam, and some other parts are put in place, the cylinders jacketed, and the parts adjusted to one another. During this work the frames are supported at the back end by jack-screws. The cylinders are brought into the proper relation to the frames by means of lines, as described in the other method of erection.

73. Placing the Boiler.—After the frames and cylinders are joined, the boiler is brought by the traveling crane and lowered to its place, and the connections between the boiler, frame, and cylinders are made. If the boiler is not perfectly round, it will not fit the saddles perfectly. After all the parts that have been erected together have been attached to the boiler, the entire engine is lifted by a crane in readiness to receive the wheels that are now rolled under and placed in their proper positions. After this the stack and pilot are put on, the boiler tested, lagged, and jacketed, and the rods, valve work, running board, cab, fixtures, and other parts are put in place very much as in the first method described.

74. Comparison of the Two Methods.—The main difference between the two plans described is, briefly, as follows: In the first plan, the boiler is the starting point, or backbone, and all other parts are built around it. In the last-mentioned method, the main part, or skeleton of the engine, is assembled and the boiler added, after which the running gear and the remainder of the engine are put in place. When the second method is used, no erecting pit is required.

SHOP HINTS.

(PART 1.)

RIGGING.

DEVICES FOR HOISTING AND MOVING.

LIST OF APPLIANCES.

1. For the handling of heavy pieces of machinery in the field, or in buildings where they are to be erected, tools and appliances known by the general name of **rigging** are used. The appliances ordinarily required are the following:

1. The winding winch, or windlass, which is a machine with a rope drum and appliances for turning the same.

2. A set of different sized tackles, in which the rope, or line, should be long enough to reach the windlass or to allow a number of men to grasp it when the blocks are the greatest required distance apart.

3. One or more screw jacks and hydraulic jacks are indispensable.

4. Slings or straps made of rope spliced together to form an endless rope.

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5. Lashings, these being pieces of rope of different sizes and lengths, with the ends stopped up, by tying or binding, to prevent their unraveling.

6. Blocks of wood, rectangular in shape and of different sizes, and timber for the construction of derricks and gin poles.

7. Wedges, both of iron and of hard wood.

8. Crowbars and pinch bars.

9. Chains and chain hoists.

10. Rollers, which are generally short pieces of iron pipe.

The articles enumerated in the first, second, third, eighth, and ninth paragraphs can usually be bought cheaper and better than they can be made. Slings, lashings, blocks, wedges, and rollers are rarely bought in the market, but are usually made.

PINCH BARS.

2. The most common form of **pinch bar** is a straight iron or steel bar, square on one end, with a flat, wedge-shaped point turned slightly to one side and the other end round and slightly tapering to form a handle, as shown in

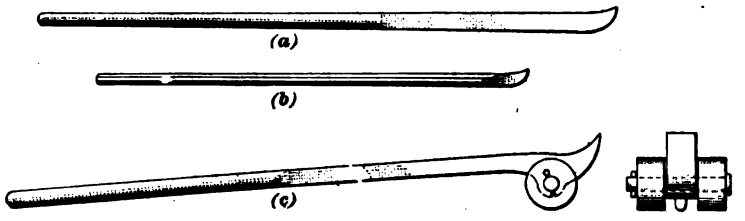


FIG. 1.

Fig. 1 (*a*). This form of bar is usually about 4 feet long, and is commonly called a **crowbar.** The smaller pinch bars, used in machine shops and in erecting machinery, are

from 2 to 4 feet long, and are made of $\frac{5}{8}$-inch or $\frac{3}{4}$-inch octagonal steel, as shown at (*b*).

A rather convenient form of pinch bar that is well adapted for lifting and moving quite heavy weights is shown in (*c*). As will be seen by referring to the illustration, the bar is mounted on two wheels, and consequently, when the bar supports a heavy weight, the bar and weight can be easily shifted. This form of pinch bar is sometimes called a **cow bar.**

USE OF SLINGS.

3. Slings are loops of rope or chain used for attaching weights to the hook of a tackle or for fastening a tackle block to some support. In order that a sling may best serve its purpose, one of several methods of fastening it to the block has to be chosen, the choice of method being influenced to some extent by the weight of the load to be lifted. For instance, the resistance of the sling is least if used single, as shown in Fig. 2 (*a*), but its greatest possible strength may be obtained by looping it over the hook as shown in Fig. 2 (*b*), thus increasing the surface of the sling in contact with the hook of the tackle block. The sling may be applied to the piece of work to be moved in the same manner in which it is fastened to the hook of the tackle block; that is, it may be either passed around singly, as in Fig. 2 (*a*), or doubled, as in Fig. 2 (*b*), the latter method being preferable owing to the absence of any danger from slipping of the sling. It is obvious that if the sling is fastened by doubling over, a noose is formed and the sling is thus tightened on the work when the free end is pulled; hence, the preference of riggers for this half-hitch arrangement.



FIG. 2.

USE OF LASHINGS.

4. Where headroom is limited, the tackle may be attached to the work by means of **lashing.** This is simply a piece of rope sufficiently long to admit of its being passed several times around the piece to be moved. Work is fastened to the tackle by first bringing the back of the hook of the tackle block in contact with the piece to be hoisted, as shown in Fig. 3, and then passing several turns of the line around the work and over the hook, the ends of the line being fastened by a knot.

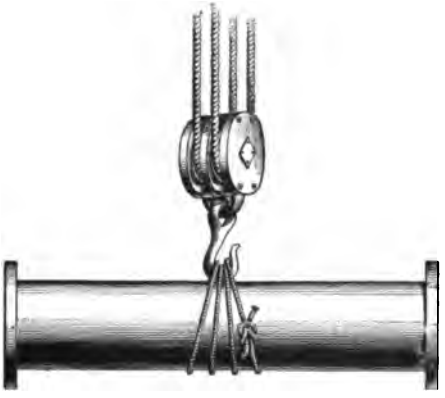


FIG. 3.

Another advantage of lashing lies in the fact that a small rope may be used ; the necessary strength is then obtained by increasing the number of turns.

INSPECTING ROPES, SLINGS, AND LASHINGS.

5. There will come a time when, from repeated use and occasional abuse, the strength of ropes, slings, and lashings will be impaired; in order to prevent any accident that may occur on account of this loss of the strength, it is necessary to know how to detect a weakened rope. The first thing to be done is to inspect the outside carefully, running over the lines from end to end, and noting if any of the strands, or yarns composing the strands, are damaged. If nothing wrong is discovered about the outside of the rope, the inside should be inspected, for the reason that a rope will

often be perfectly sound on the outside, but utterly bad inside. The inside may be inspected by taking the rope in both hands and untwisting it sufficiently to expose the inner surfaces that have been chafing against one another. Then, if the life or utility of the line has been impaired by long use, a considerable number of broken fibers will be found; if in a bad state, they may have been reduced to powder. If broken fibers are discovered, the use of the rope should be confined to loads not heavier than half the load it formerly could stand; if a considerable quantity of powder is found, the line should be condemned at once as unfit for use.

Slings and lashings, as a general rule, are ruined by external chafing received when moving rough castings, etc., and hence their safety can be determined from their external appearance. Ropes or lines, on the other hand, when used for tackle blocks, receive the greatest wear on the inside, owing to the chafing and grinding of the strands when passing over small pulleys under heavy strains.

CHAIN HOISTS.

6. Chain hoists, as a general rule, are best adapted to lifting heavy loads where the help available is scarce, since, owing to the way in which they are geared, they require very little power. There is, however, a great range in the efficiency of chain blocks, varying from 18 per cent. with the common *differential chain hoist*, where it takes considerable power to lower the load, to 79 per cent. efficiency in the case of the *triplex hoist*. One great advantage of chain hoists lies in the fact that they may be stopped at any point; that is, the load will remain in a state of rest, without securing the chain in any way, until set in motion again by the operator. With a tackle this cannot be done, since it is necessary to fasten the free end of the line to some stationary object in order to hold the load; this, of course, is often a drawback to the use of a tackle, and a great point in favor

of the chain hoists. To offset this, we have the fact that, with long usage, the iron in the chain links becomes crystallized, and hence is liable to break suddenly even under a moderate load. The effects of crystallization can, however, be remedied to a large extent by a thorough annealing of the chain. This can most readily be done by coiling the chain after removing it from the blocks, and then building a charcoal fire around it. This should be done in the open air; no blast should be applied to the fire. After the chain has been heated cherry red, it should be placed in an iron vessel, the bottom of which has been covered with powdered charcoal. Then cover the chain with the same substance, close the box, and allow the chain to remain there until cold. It may then be rove through the blocks again, and will be nearly as good as when new.

SPLICES.

7. Definitions.—Splicing is the operation of so joining two pieces of rope as to obtain one continuous piece with no appreciable increase of diameter at the splice. There are several kinds of splices, but the principal ones are the *short splice*, the *long splice*, and the *eye splice*.

The principle of all splicing consists of joining, or *marrying*, the strands, thinning them out and tapering them so that the diameter at the splice is the same or only slightly greater than that of the rope itself. In the long splice, no increase in diameter is allowed.

8. Materials Used for Ropes.—Until comparatively recent years, all ropes were made of vegetable fiber teased out and spun into suitable form either by hand or machinery; but since the introduction of iron, and particularly of mild steel, into the rope-manufacturing industry, steel rope is rapidly superseding all other kinds of rope for certain classes of work. For many purposes, however, fiber ropes are still used and can never be replaced by steel ones; they are made,

for the most part, either of hemp, manila, or coir (cocoanut husk fiber). First, the fibers are spun into yarns, then the yarns into strands, and, finally, the strands into rope. The methods of splicing described and illustrated here apply only to these fiber ropes.

9. Splicing Instruments.—The only instruments necessary for making a splice are a **marlinspike** and a knife. The former is made of either iron or hard wood, is from 12 to 14 inches long, and about 1 inch in diameter at the thick end, the other end being sharpened to a blunt



FIG. 4.

point about as shown in Fig. 4; it is always operated by the right hand, while the left encircles the rope. After pushing the point through the rope, between the strands that are to be separated, the thick end is placed against the body of the operator; then, using both hands, the rope is untwisted so as to render the work of opening the strands comparatively easy.

10. Making a Short Splice.—Unlay, that is, split open, the strands at the end of each rope for a distance about as shown in Fig. 5; this distance depends entirely on

the diameter of the rope, but as the proportion will be the same for all diameters, the illustration serves as a general guide. Be sure to unlay enough; a few inches too much is better than too little, as the ends have to be cut off anyway. Then, place the two ends together as shown at (*a*), so that each strand lies between two strands of the other rope. Now, hold the strands *x*, *y*, *z* and the rope *A* in the left hand; if the ropes are too large to hold in this manner, fasten them together with twine; then take one of the strands, say *n*, and pass it over strand *y*, and having made an opening, either with the thumb or with a marlin-spike in the manner illustrated in Fig. 4, push the strand *n* through *x* and pull it taut; this operation is known as *sticking*. Proceed similarly with strands *m* and *o*, passing each over the immediately adjoining strand and under the next one. Perform precisely the same operation with the strands of the other rope, passing each strand over the adjoining one and under the next, thus making the splice appear as at (*b*). Now, in order to insure security and strength, this work must be repeated by passing each strand over the third and through under the fourth; then, after subjecting the splice to a good stout pull, cut off the ends of the strands, and the finished splice as shown at (*c*) is obtained.

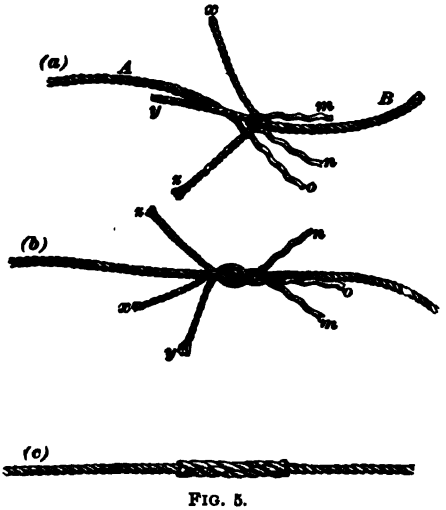


FIG. 5.

In slings and straps used for heavy work, the strands should be passed twice each way, and one-half of each strand should be *whipped*, or bound, with twine to one-half

of the rest, thus preventing the strands from *creeping through* when the splice is taxed to the full capacity of the rope.

11. Making a Long Splice.—In the short splice, the diameter at the joint is rather greater than that of the rope, for which reason it is not a suitable splice where the rope is to be used in tackles and pulley blocks, or in places that will not admit anything larger than the rope itself. In such cases the long splice is used. When properly made, the untrained eye can hardly distinguish it from the rest of the rope. To make the long splice: Unlay the ends as before, but about three times as far, and place them together as

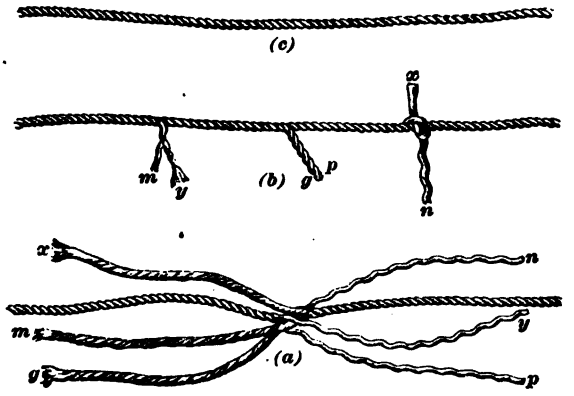


FIG. 6.

shown at Fig. 6 (*a*), in the same manner as for the short splice. Then unlay one of the strands of the right-hand rope, say x, and in the groove thus made lay the strand of the left-hand rope, taking good care to give the strand the proper twist, so that it falls gracefully into the groove previously occupied by the strand x. Do likewise with the strands y and m, unlaying y gradually and in its place laying the strand m: the result is shown at (*b*). Now, leaving the middle strands p and g in their original positions, cut off all

the strands, as shown at (*b*); then relieve strands *n* and *x* of about one-third their yarns, and with what is left cast an overhand knot, exactly as shown; no other kind of knot will do. Pull this knot taut and dispose of the ends, as in the short splice, by passing them over the adjoining strand and through under the next, cutting off a few yarns at each *stick*. Proceed similarly with strands *p* and *g*, and *y* and *m*. The splice, when it is completed, appears as at (*c*). Sometimes the overhand knot is made without first thinning the strands, and then split and the half strand put through as described, but by doing so the surface of the splice is never as smooth as by the other method, which, for strength and neatness, is second to none.

12. Making an Eye Splice.—Another splice, and one that is as common and useful as the two already

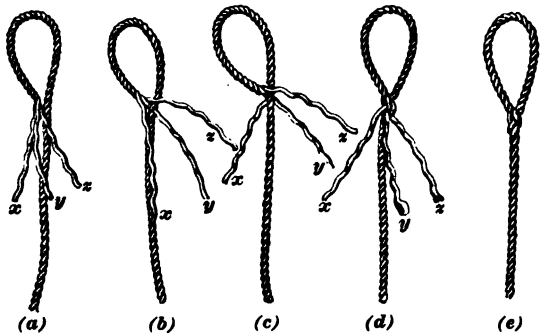


FIG. 7.

described, is the eye splice illustrated in Fig. 7. To begin this, unlay the end of the rope about as far as for the short splice, and bend into the required size of eye, as shown at (*a*). Then tuck the end of the middle-strand *y* under one of the strands of the standing part, having previously made the necessary opening with the marlinspike, and pull tight, getting what is shown at (*b*). Now push the strand *x* from behind, and under the strand on the standing part next

above that under which the middle strand *y* was passed, so that it will come out where *y* went in, getting what is shown at (*c*); then pass the third strand *z* under the remaining free strand in the standing part, next to the one under which *y* was passed, getting (*d*). Now pull the strands taut, and from each cut out one-third of the yarns, and tuck each one under its corresponding strand twice more; give it a good stretching, cut off the ends, and thus complete the splice, as shown at (*e*).

KNOTS, BENDS, AND HITCHES.

13. In Fig. 8 are illustrated a few methods of making knots and bends, applying slings and ropes to hooks, barrels, etc., and a few other wrinkles useful to those engaged in workshops. Should a rope be too long for some temporary purpose, do not cut it, but arrange it as at (*a*); if several *bights* are laid up to shorten the rope to the required length, pass the standing part through and over the ends of all, and pull tight. At (*c*) is shown how a sling or strap should be applied to a hook when the rope spreads away to its load; this hitch will prevent the sling from slipping in the hook, in case the load should come in contact with some obstruction while being hoisted. At (*b*) and (*d*) is shown how a smaller rope should be secured to one of greater diameter. The **Blackwall hitch** is illustrated at (*e*); except for very light loads, this should be made with the end twice around the hook (called a **double hitch**), as in the figure. Experience has proved that this is the safest way, since with only one turn, the end is liable to creep when subjected to a heavy pull, especially in damp weather, when the moisture absorbed by the rope acts as a lubricant. When a rope is too long to conveniently secure its end to a tackle, a bight of it twisted as at (*f*) is very handy and useful. To make this hitch, commonly called a **cat's paw**, take hold of the rope with both hands at places about 2 feet apart, and twist it two or three times each way; then apply the ends of the loops thus made to the hook. The twisting prevents the

rope from becoming jammed, and the hitch is very easily undone. At (*g*) is shown a **timber hitch,** so simple that

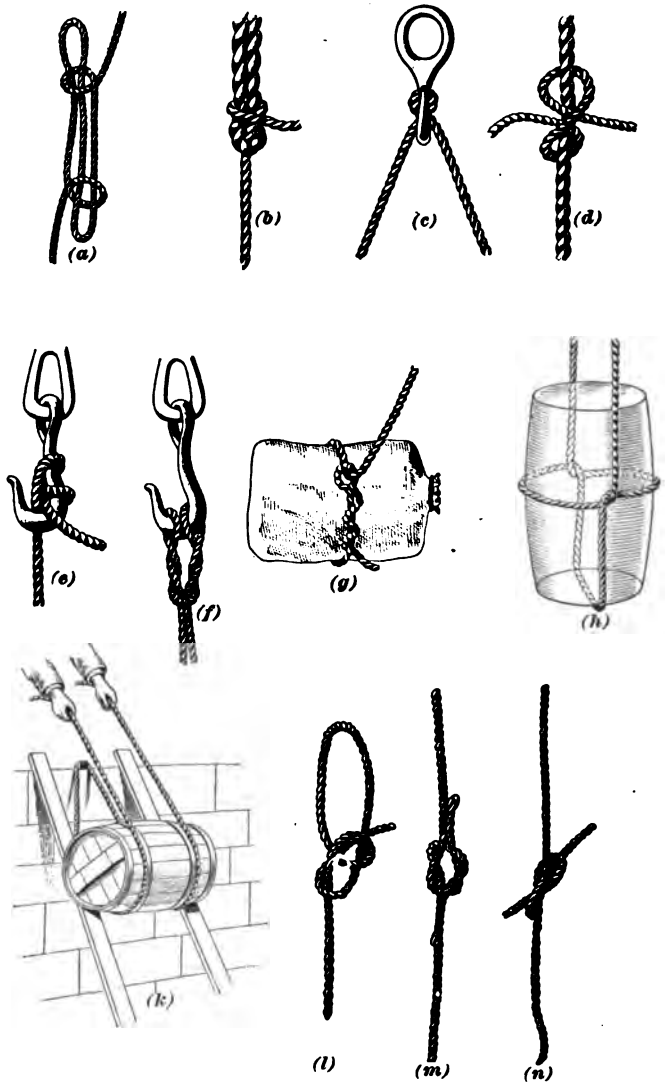


FIG. 8

explanations are unnecessary. At (*k*) is shown how to apply a rope to a barrel or similar vessel when, for some reason, it

is desired to hoist it in a vertical position. At (*k*) is shown what is known as a **parbuckle**; this hitch is used for raising a heavy cask or similar load with a single length of rope.

A very useful knot that should be mastered by every mechanic, and by all persons in any way connected with shipping, is shown at (*l*); by seamen, this is known as the **bowline knot.** To make it, take the end of the rope in the right hand and the standing part in the left; lay the end over the standing part, then, with the left hand, turn over the end a bight (a loop, or turn) in the standing part, pass the end over and around the standing part, and through the bight again, thus completing the knot; all this is shown with perfect clearness in the illustration. Probably the most common knot used for tying two ropes together is the **square knot** shown at (*m*). This should always be made in the manner shown, and never as shown at (*n*), which is sometimes called a *granny's knot.*

ERECTION OF A DERRICK.

14. Description of the Derrick.—A common form of **derrick** is shown in Fig. 9. It consists of a *mast a*, the lower end of which is set into a *base b* that is secured to the timber framing *c* shown in the illustration. The upper end of the mast carries the so-called *derrick head d*, to which the *guy ropes e*, *f*, *g*, and *h* are fastened. These guy ropes are fastened to stakes driven into the ground, or to any other immovable objects that are conveniently located, and serve to steady the mast. The mast has pivots at both ends that enter sockets in the base and in the derrick head, and allow the mast to be rotated. The *boom i* is pivoted to the mast at *k*, and can be raised or lowered by the *tackle l.* The tackle *m* is used for hoisting weights.

When the mast alone is used in hoisting, i. e., when no boom is furnished, the mast is called a **gin pole.** When the upper end of the mast and boom are tied together by a horizontal member, the whole device is called a **crane,**

and is usually fitted with a traveling carriage on the horizontal part, or *gib*.

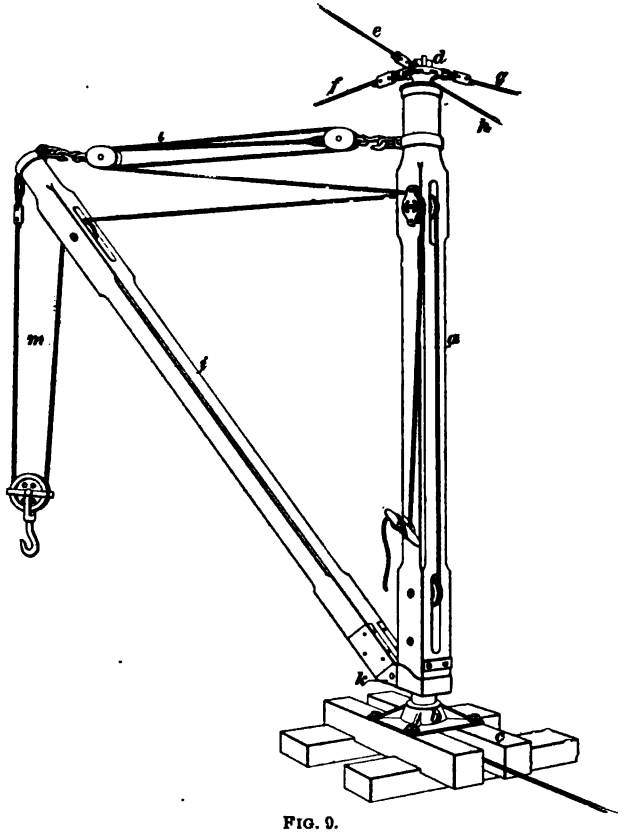


FIG. 9.

15. Erecting the Gin Pole.—When it is desired to erect a tall derrick, it will generally be necessary to put up a gin pole first to assist in raising the mast, but if the derrick is low, its boom may be used for this purpose. One method of erecting the gin pole is to slip a bar of iron *a* through the hole in the lower end and secure it to suitable stakes *c*, as shown in Fig. 10. The free end of the gin pole is then lifted from the ground and placed on the X-shaped brace *e*. The guys *f*, *g*, *h*, and *i* are then attached to the

upper end *d* and are laid out on the ground ready for use. The men now raise the gin pole *b* by means of pike poles and advance the support *e* toward the lower end. When the free end has been raised some distance from the ground, the ropes *f* and *i* may be pulled, and thus help to raise the

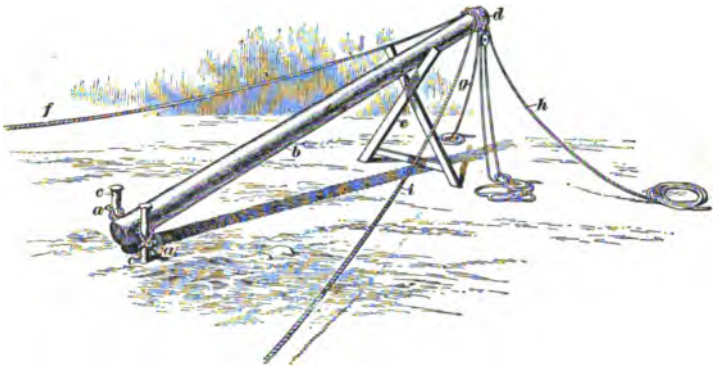


FIG. 10.

gin pole to a vertical position; at the same time, the men who attend to the guys *g* and *h* must see that it does not shift from the desired position. Usually only one man is required for each end of the guys *g* and *h*, since he can wind the rope about a stake, and then easily prevent the gin pole from moving too far.

16. Erecting the Mast.—After the gin pole has been raised into an upright position and the guys have been fastened, it may be used for lifting the mast, as is shown in Fig. 11, in which *a* represents the gin pole, the lower end of which is lashed to the stakes *c*. The base for the derrick having been located and fastened to the timbers *b*, *b*, the mast *d* is hoisted into position by means of a rope fastened a little above its center and passed over the pulley *e* on the end of the gin pole. The other end of this rope *f* may be handled by hand if the mast is not too heavy, or by a suitably located winch or crab if the mast is of considerable weight. The derrick head *g* should be placed in

position and the guys attached before the mast is raised. The lower end of the mast is now lowered into the base,

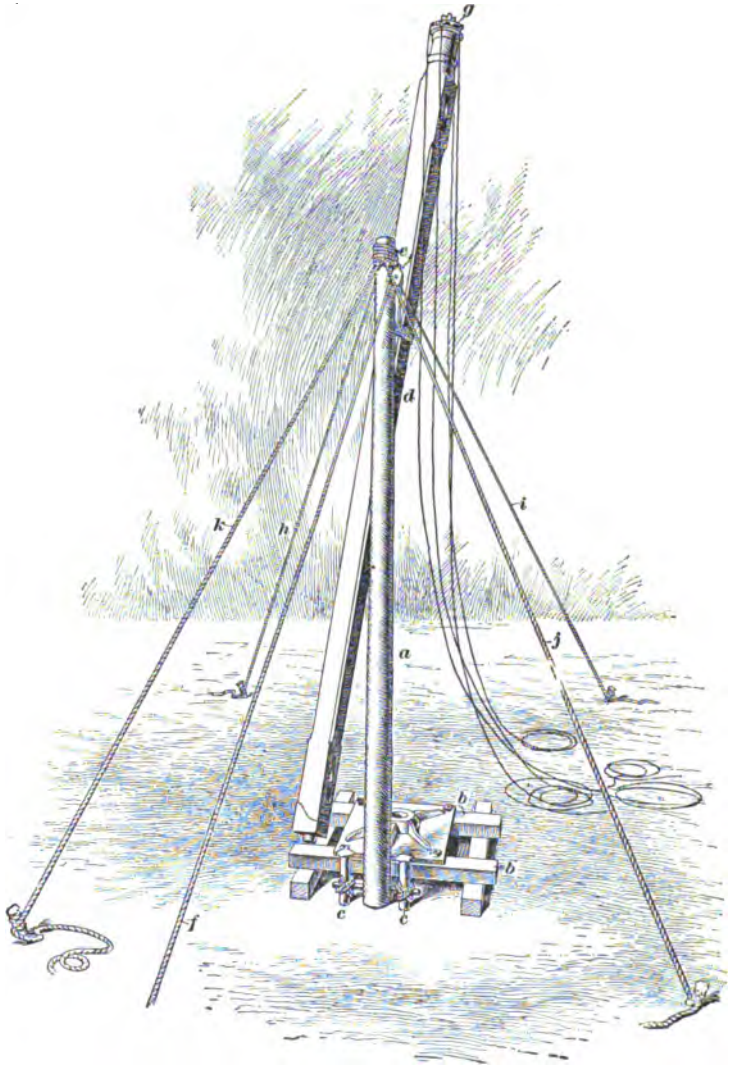


FIG. 11.

after which the guys attached to the head *g* are tightened and fastened in position. The temporary guys *h*, *i*, *j*, and *k*

for the gin pole are usually of manila or hemp rope, while the permanent guys for the mast are made of wire rope.

17. Placing the Boom.—After the mast has been properly guyed and the gin pole has been taken down, a hoisting rope is passed over the pulleys at the top of the mast; a hitch is then made around the boom and it is raised until the bottom end can be swung into the knee, where it is secured by its pin. The ropes are then all reeved through their proper pulleys and the derrick is ready for work.

Large derricks are generally erected by the aid of a separate gin pole, as just described. In the case of a very large derrick it is sometimes necessary to erect a gin pole of a height such that the men can handle it, and use this for setting the boom on end, which is then used as a gin pole for lifting the mast. In some cases two separate sticks of timber are used as gin poles, a short one, less than one-half the height of the mast, being used to set a gin pole about two-thirds the height of the mast; this second gin pole is then employed for setting both the mast and the boom. Derricks so large as to require two gin poles for their erection are rarely used except on permanent work.

18. Erecting a Small Derrick.—With small derricks, it is rarely necessary to use a gin pole for raising the mast, as the boom is generally light enough to be erected as a gin pole, and is then used for raising the mast. After the mast has been raised and securely guyed, the mast itself is used for swinging the boom, which up to this time has served as a gin pole, into position.

19. Dismantling the Derrick.—When the work has been finished and it becomes necessary to dismantle the derrick, the boom is hoisted up to the mast, and is detached from the knee. Stakes are then driven into the ground and the lower end of the boom is lashed to them; the boom is then used as a gin pole for lowering the mast. The boom itself is lowered afterwards by paying out two of its temporary guys until it can be caught on a support similar to that shown at *e*, Fig. 10.

MISCELLANEOUS OPERATIONS.

CLEANING WORK AND CASTINGS.

THE SODA KETTLE.

20. Description of the Kettle. — All shops have more or less work that must be cleaned so as to be free from grease. This is often a troublesome task, involving the expenditure of time and energy. The greater the irregularity of the pieces, the more trouble there is experienced in cleaning them.

A very convenient method of quickly and easily cleaning small parts of machines, tools, or machined parts is to wash them in hot soda water. The most convenient receptacle for this mixture is known in the shop as a **soda kettle.** This is often a shop-made affair, but embodies the main features of the kettle illustrated in Fig. 12. This soda kettle, which is built by a well-known tool builder, consists of a cast-iron kettle *a* containing a coil of steam pipe for heating the soda water. Live steam enters the coil when the globe valve *b* is opened, and the exhaust steam leaves through the pipe *c*, which is provided with a globe valve. A by-pass pipe *d* having a globe valve is connected to the exhaust pipe; if the globe valve in the exhaust pipe is closed and the valve in the by-pass pipe is opened, the pressure of the live steam will force the water

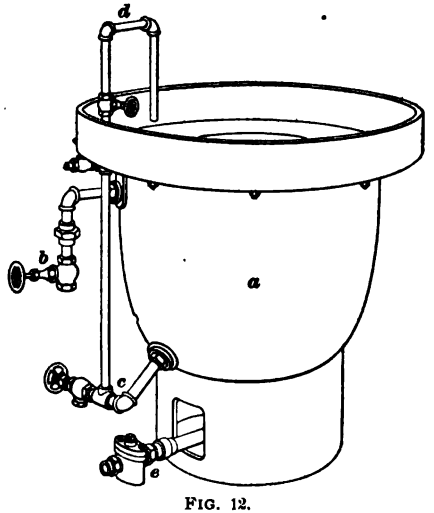


FIG. 12.

of condensation in the bottom of the coil into the kettle. A drain cock *e* is used for emptying the kettle.

21. Operation of the Kettle.—In use, the kettle is filled about three-fourths full of clean water to which is added about $\frac{1}{20}$ its volume of sal soda; the mixture is then heated as hot as the steam will heat it. A wire basket, or an iron pail or bucket having the bottom punched full of holes, is provided for holding small pieces while dipping them into the soda mixture. Suitable hooks made of small iron rod may be used to dip single pieces into the kettle. A pair of pick-up tongs and one or two hooks should be kept near the kettle, since pieces are sometimes dropped into it and must be fished out. Work covered with soft grease or oil and chips is cleaned by putting it into the basket, which is then dipped into the hot water. Work that may be covered with oil that has dried on it often has to be soaked in the solution for some time, and a part of the dried oil then has to be scraped off ; the work is now given a further soaking, which is generally sufficient to remove the rest of the dried oil. Work cleaned in the hot soda water dries quickly and will not rust.

PICKLING SOLUTIONS.

22. Sulphuric Acid for Pickling.—The surfaces of castings, drop forgings, and many of the materials used in the construction of machinery require cleaning or preparation before they can be used. Much of this cleaning is done by pickling the work in such mixtures as, by experiment, have been found to be most effective. Several of these solutions are given below, and the user can, by experiment, determine which of these is best adapted to his needs.

Oil of vitriol, or sulphuric acid, is one of the most common acids used for pickling. It is generally transported in glass carboys, which are securely boxed up. The acid is handled in small quantities around the works in glass, earthen, or lead vessels. It is used in the proportion of about 1 part of acid to 4 parts of water, for cleaning sand and scale from

iron castings, although some use a larger proportion of water. Pure sulphuric acid will not attack iron, but the dilute acid, or the acid mixed with water, will do so.

23. The Pickle Bed.—The cleaning is generally done in what is called a **pickle bed,** which consists of a lead-lined trough for holding the solution. At one side of it is a sloping wooden platform, so that the solution will flow from it to the trough. The castings are piled upon this platform and the solution is poured over them with a ladle. They are allowed to lay over night ; it will then be found that the acid has attacked the surface of the iron sufficiently to loosen the sand, much of which is washed away with water. The castings are further cleaned with wire brushes and old files.

24. Hydrofluoric Acid as a Pickling Mixture. Wrought iron that is badly scaled in forging may be cleaned with a solution of 1 part of sulphuric acid to 10 parts of water ; after pickling, the work should be cleaned in hot lime water. Another, and in many respects, better, solution is composed of 1 part of hydrofluoric acid to 10 parts of water. This is kept in a wooden vat ; the castings are immersed in it for 2 or 3 hours. Hydrofluoric acid does not, like sulphuric acid, attack iron, but, instead, attacks the sand directly and eats it, as well as the hard magnetic oxide (the scale). About half as much hydrofluoric acid is used as would be needed of the sulphuric acid, and the work is done in about one-fourth the time. The pickling vat may be filled and used two or three times before adding more acid. Drop forgings are often covered with a thick, hard scale that may be removed by dipping them in this mixture, then washing them in clear water. Care should be taken to keep this acid from the hands, as it burns severely in a few hours. If it is spilled upon the hands, they should be washed in water mixed with aqua ammonia, or some other alkali, in order to prevent injury.

Brass castings are pickled in a mixture of 1 part of nitric acid to 5 parts of water and washed thoroughly after pickling.

COMPRESSED AIR FOR CLEANING.

25. In shops having compressed-air service, a $\frac{1}{2}$-inch rubber hose with a $\frac{3}{8}$-inch nozzle attached to it forms a convenient means of cleaning many pieces of work that are so shaped that it is difficult to reach every part with the hand. The blast is simply turned on the piece to be cleaned, and most, if not all, of the loose dirt is blown off. An air hose will be found very useful in the tool room for cleaning the shelves, racks, and drawers, and may even be used advantageously for rapid cleaning of some tools. The disadvantage of the air blast lies in the fact that it scatters the dirt all over the vicinity.

PROTECTIVE COVERINGS FOR METALS.

GALVANIZING.

26. Preparing the Iron for Galvanizing. — Galvanizing iron consists in providing it with a tightly adhering coating of zinc. This makes it practically waterproof, and it is of good advantage even if afterwards coated with protective paint. All castings that are continually exposed to the weather should be galvanized, unless otherwise protected.

The process consists in the preparation of the casting or other articles to receive the coating, and the actual immersion in the bath of melted zinc. The castings are first freed from as much sand as possible in the foundry. Malleable castings are usually clean enough for this purpose when they leave the soft-casting cleaning room. Next, they are placed in large vats containing dilute sulphuric or hydrofluoric acid, the latter being used only in obstinate cases, as a rule. Here they remain until the coating of oxide is thoroughly removed. For large work, the vats are sometimes 30 feet long, 6 feet wide, and 4 feet deep, and have steam pipes to warm the solution in cold weather, though usually the chemical reactions warm the pickle sufficiently. The castings may remain in the pickle over night, being stirred frequently so that pockets of gas that have formed may not

cover a spot and prevent the acid from touching it, as these spots would not galvanize properly. Castings are also repeatedly taken out and scratched with a chisel or old file to note how the action of the acid progresses. When the process is finished, the acid may be drawn off into another tank, preferably by means of a steam siphon, or it may, as is usually the case, be left in the tank, and the castings transferred into a second tank containing clean, warm water. Small castings are always wired together or put into perforated wooden boxes so that they cannot be lost. In this second tank the acid is washed off, and the pieces should be thoroughly

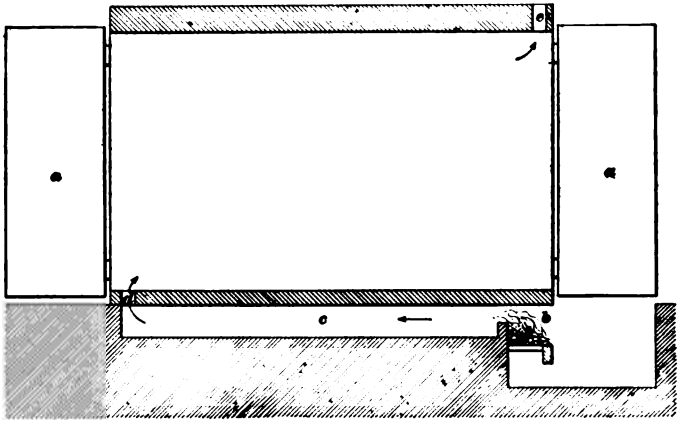


FIG. 13.

examined. The work could now go to the drying oven and then into the zinc pots, but an improved method introduces another pickling in dilute hydrochloric acid, in which the work remains long enough to be again attacked thoroughly. When lifted from this solution the castings are placed in a large drying oven, shown in Fig. 13, to be dried and heated preparatory to the galvanizing process. These drying and heating ovens are usually constructed of brick and have doors, as shown at *a*, *a*, of sheet iron on each end, each door being the full width of the oven. This facilitates the placing and removing of the material and enables the operation to be performed so quickly that little heat is lost. The fire is

built on the grate at *b*, from which the gases with the heat pass through the chamber *c*, heating the oven from below, and into the oven through the opening *d*, and finally out again through *e*.

27. Coating the Work With Zinc.—It seems that the second pickling in hydrochloric acid impregnates the surface of the iron with a chloride of iron, which, on being dried, protects the iron surface from rusting. Again, the dried chloride of iron, on touching the melted zinc, is volatilized, leaving a clean surface of pure iron behind, and this surface in a rough state increases the tendency of alloying with zinc. The consequence is that no difficulty is experienced in

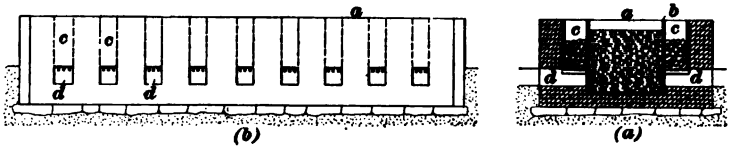


FIG. 14.

getting the zinc to adhere; hence, when the castings come from the heating oven, they go directly into the bath of melted zinc. This bath is practically a tank furnace, one form of which is shown in Fig. 14 (*a*) and (*b*). A tank of suitable size, according to the character of the work treated, is made of heavy steel plates riveted to an angle-iron frame, as shown at *b*, Fig. 14 (*a*).

This tank is bricked into a furnace arranged with fire-pots at regular intervals, as shown at *c*, *c*, which are required to keep the zinc at the proper temperature. Air drafts, as shown at *d*, are provided for each fire-pot.

It is important that the castings coming from the drying oven lose no heat, for such a loss has the effect of chilling the bath, which means delay in getting out the work. Small castings are also kept wired together in the zinc bath. When taken out, the surplus zinc is shaken off and the castings are sometimes quenched in cold water, although this may injure the castings, sometimes cracking or breaking them. Large castings are handled with a tackle suspended above

the tank, while the surplus zinc is taken off with a trowel and wet broom. Small castings, if it is impossible or undesirable to wire them together, are placed in large dippers made of coarse wire-screen material, and all dipped into the molten zinc. Some galvanizing works do not use drying and heating ovens, but take their castings in small quantities directly from the acid bath to the zinc bath, and let this heat them. This practice is not a very good one, as it deteriorates the zinc in the bath and leaves a bad looking surface on the casting. After the castings are galvanized they are sometimes carried through the quenching water on a chain carrier, and at this point the inspection should be made and faulty work returned to the tanks for regalvanizing. During the galvanizing process, dry sal ammoniac is thrown on the work as it is dipped in and out of the bath of zinc, to help the alloying process. Dense fumes of sal ammoniac fill the room, but they are not seriously dangerous to health. It is well to have some grease on the zinc bath, as this keeps the zinc from oxidizing rapidly and also assists in the alloying of the zinc with the iron surface to be coated. The castings finally go to the warehouse for shipment.

28. Recovering the Waste Zinc.—The oxidation of the zinc is one of the most serious things with which the galvanizer has to contend, as it gradually renders the zinc unfit for use. A certain amount of iron is removed from the castings and from the tank. This iron enters the zinc bath, and, uniting with the zinc, forms an alloy called *dross*, which settles to the bottom of the tank, and if left there will soon form a hard cake and ruin the tank. The continuous application of excessive heat will result in the blistering and burning out of the steel plates. Once or twice a week, therefore, a large iron scoop, shaped like a large snow shovel, and operated from above by the tackle, is pushed down into the tank, and the dross lifted out. Perforations in the scoop allow the good zinc to drain off, and the dross is poured into iron molds, where it quickly solidifies. It is then dumped and piled for sale to the zinc-refining companies. When it is understood that sometimes one-fourth of the

whole bath is dross at the end of a week of continuous galvanizing, and that the dross is 90 per cent. zinc, the seriousness of the loss becomes apparent. The dross can be refined again by melting with lead and rabbling with green poles, but it hardly pays galvanizers to attempt this, as the zinc-refining companies have special facilities for the purpose and do the work at moderate cost.

The skimmings of the zinc bath and floor sweepings should also be preserved, as they contain considerable zinc. Much of the zinc is recovered from them by treating the material in a special roasting furnace, as shown in Fig. 15, with an inclined hearth, shown at *a*. Small quantities are treated at a time, the particles of scattered zinc collecting as they run down in the little well shown at *b*, at the bottom of the pan, from whence the zinc is tapped through the opening shown at *c* into the vessel shown at *d*. What remains of the roasted material is barreled and sold. The furnace here illustrated has a firing door *e*, an ash door *f*, grates *g*, a flue *h*, a hood *i*, and an opening from the hood *j*, through which the fumes from the zinc pass. This process is very trying to the immediate neighborhood on account of the fat used to cover the bath of the zinc, much of which finds its way into the skimmings and results in very bad-smelling fumes. The roasting should therefore be done only at night, unless some provision is made for the disposal of the fumes.

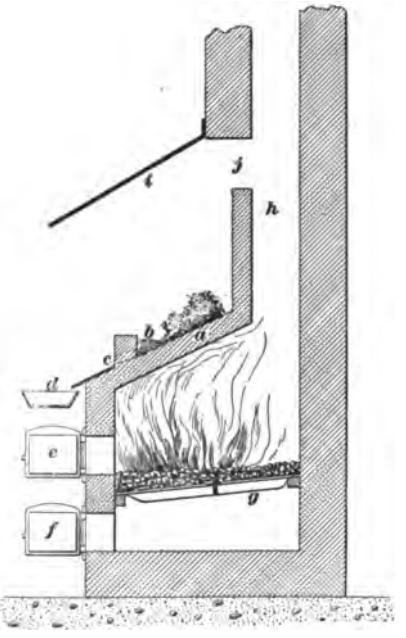


FIG. 15.

29. Some Precautions and Suggestions in Galvanizing.—With hollow castings, pipe, etc., great precaution must be taken to keep out of the way, for if any moisture has remained in the pipe and comes in contact with the hot zinc, it will cause an explosion, throwing quantities of the melted zinc from the end of the casting with great force.

The same holds true in quenching a pipe in cold water, although here the projected water is not so serious. Glycerine is often used to add to the grease on the melted zinc, as it is said to give fine results when good color and crystallization on the surface are wanted.

A good way to prevent the dross from adhering to the bottom of the tank, as well as to facilitate its removal, is to introduce a quantity of lead into the zinc bath. Lead does not alloy with either zinc or iron; it has a greater density than either, and, therefore, sinks to the bottom, forming a liquid cushion on which the dross and other impurities float.

TINNING.

30. Tinning by Dipping the Work Into Molten Tin.—Tinning castings differs from galvanizing only in the substitution of tin for zinc and in general carrying on the process on a much smaller scale. The work when small is all put into wire baskets and pickled, after which the basket with the well-pickled castings is slowly lowered into the bath of tin. This is usually done with a small tackle, and when thoroughly tinned the basket is raised and the tin allowed to drip off. The castings are then dumped into a wooden chute, shown in Fig 16,

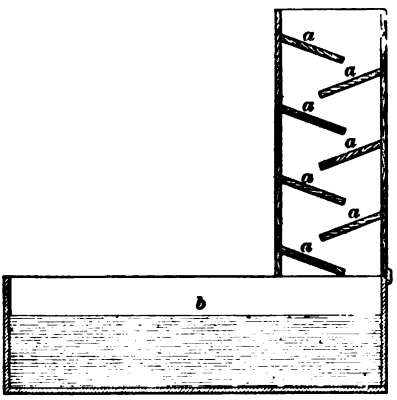


FIG. 16.

which has inclined wooden shelves, as shown at *a*, which throw the castings violently against each other as they descend. The consequence is that the remaining surplus tin is jarred off, the pieces cool without remaining in contact with each other, and are quenched practically singly as they fall into the water shown at *b*. They are finally rolled in sawdust in order to dry them thoroughly, and are then packed for shipment. The tinning furnace ordinarily used resembles a crucible furnace, and is illustrated in Fig. 17. A firebox is shown at *a*, with its ash-pit at *b* and flue for escaping gases at *c*. The iron kettle shown at *d* is in direct contact with the flame, thus heating readily. Above the kettle is the hood shown at *e* for collecting the fumes and directing them toward the opening, shown at *f*, into the chimney.

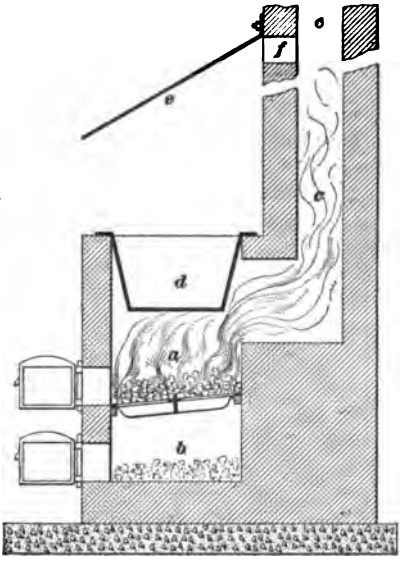


FIG. 17.

31. Tinning by the Cold Process.—When block tin is dissolved in hydrochloric acid and a little mercury, an alloy is formed that can be readily used in tinning articles without heating either the tin or the work. Some make the alloy of 1 part of tin, 6 of mercury, and 2 of zinc, by weight. The tin and mercury are mixed together until a soft paste is formed. The articles to be tinned should be cleaned by some of the methods previously explained, and then rubbed with a rag dampened in hydrochloric acid. The alloy should be applied to the surface at once and rubbed with the hydrochloric acid. By this method it is very easy to cover iron, steel, or copper with a complete, but thin, coating of tin.

FILLING AND PAINTING MACHINE TOOLS.

32. Most machine tools are finished by giving them a coat of paint. The surfaces of the castings are cleaned first in the foundry scratch room, and any remaining dirt or irregularities and unevennesses of joined parts are removed during erection by chipping and filing so far as may be necessary to make a good surface. The shop painter next goes over the surfaces with a filler, which is a kind of thick, heavy paint, very adhesive and quick-drying. It is applied with a putty knife, as it is about as thick as very soft putty or freshly opened white lead. This filler hardens rapidly when exposed to the air. The filled surfaces are then smoothed by wetting and rubbing them with a piece of grindstone or a piece of a broken emery wheel, or by simply rubbing them with coarse sandpaper. When the smoothing has been finished, one or two coats of paint having the desired color are applied. Green paint is preferred by some builders and shop superintendents, as it gives a lighter appearance to the shop than black paint. Green and even lighter paints are much used for machine tools, and if the painted surfaces are covered with a varnish that will resist oils, they are easily kept clean and the general appearance of the shop is thus much improved. Steel-gray metallic paint is a favorite paint with many builders on account of the handsome appearance it gives to the machines.

NOTES ON SHOP ECONOMY.

COST OF CONSTRUCTION.

33. Large Quantities Can Be Made at Low Prices. The question of cost in constructing a machine or device is one of great importance in machine-shop operations, since the question of whether to build or not to build depends on it. It is an every-day occurrence for men to go to a machine shop and ask to have a part of a tool or a machine made, and to be told that the piece would cost more than the price paid

for the whole tool or machine when it was new. The reason for the low cost of the whole machine and the seeming high price for the single piece lies in the fact that the maker of the machine or device had special tools for every operation and trained help to do the work, which was done in large lots, perhaps hundreds at a time, and could thus be produced very cheaply. But the man that is called on to make single parts, one at a time, either has to use such tools as he happens to have, or has to make special ones that will be of no use on any other work, and that must be paid for by the customer.

The cost of constructing the model of a typewriter, bicycle, sewing machine, or any similar piece of mechanism frequently runs up into thousands of dollars, since every part is made by hand; but, the manufactured article, where every part is made in large quantities on the interchangeable plan, and with special tools, fixtures, and workers, is built for a few dollars.

34. Cost of Pattern Work.—In foundry work the same condition exists. A customer frequently wants some comparatively simple casting, weighing perhaps only a few pounds, but which requires the making of a special pattern. Evidently the cost of the pattern must be included in the price charged for the casting. Then, though the value of the iron may be only ten cents or less, it may cost five or ten dollars to make the pattern for this small casting; and this must be paid for by the customer. As a matter of course, if a large number of castings are to be made from one pattern, the cost of the pattern is distributed among so many castings that the cost of each is quite low. For instance, it costs several thousand dollars to make the pattern for a stove, but the finished stove can be sold at a very low price on account of the large number of castings made from each pattern.

35. Cheapening by Duplication. — If only one machine or engine of a kind is to be built, the work must be done with such tools as are at hand and such other ordinary

tools as may be bought or made on the premises; but, if a large number of the same kind of engine or machine is to be built, special tools can be provided for the different operations and the same operation can be performed on all the pieces in succession, thus saving the time that would be required for changing tools and machines if each separate piece were finished all over at one time. It should be kept in mind that it costs just about as much to rig up a machine or get it ready to perform an operation for a single piece as it does to do the same thing for a dozen or a hundred pieces; hence, wherever it can be done, the whole number of the same operations should be performed before making a change. This statement applies to all parts and all stages of the work, from starting on the rough forgings and castings to inspecting and painting.

TIME ELEMENT IN WORK.

36. Rate of Speed in Doing Work. — Any one engaged in mechanical work, be he apprentice or journeyman, should always have the clock in mind. This statement does not refer to watching the clock for quitting time, which comes quickly enough to those really interested in their work, but to the time element in connection with the work. No doubt the principal object is to do the work right, but between two men, each doing it equally well, the one that completes the work in the shorter time is the better man, the one who should and generally will receive the higher wages, and the one who is less liable to be "laid off" when business is dull. It is well, therefore, for a person to cultivate the habit of working as rapidly as the character of the work will permit, first making up his mind as to the time a piece of work should take, and then doing his best to shorten that time. Some think that they will first learn to do the work well regardless of time, and afterwards learn to do it quickly; but this plan is open to the practical objection that having once learned a rate of doing work it is hard for us to change that rate. While the quality of the work must

always be the first consideration, the time element should never be disregarded. Thus, an apprentice may think, because his pay is small, that only a small amount of work should be expected of him, and, hence, may conclude that he will increase his speed when he becomes a journeyman or receives a higher compensation. He should consider, however, that the money he receives is the smallest part of his compensation, and that the trade he is learning, the manual and mental training, and the experience that he is receiving form the greater part. Such a boy may learn to do a piece of work well, but is not likely to receive the highest rate of compensation when he becomes a journeyman, since his rate of speed generally remains abnormally low.

37. Standard of Quality and Speed of Work.—In performing a certain operation on a piece of work, or in fact in doing any kind of work, it must always be remembered that work, and, consequently, the value of the producer, is measured by two different standards, the *mechanical* and the *commercial*. The **mechanical standard** measures the degree of skill with which the work is executed and the excellence of the design; in other words, it is a measure of the quality of the work. The **commercial standard** takes account of the labor cost, and the person that reduces this factor to the lowest limit compatible with the degree of mechanical excellence that the nature and purpose of the work requires, is the one that will, and properly should, receive a higher compensation for his services than the person that can do a good job only when he is given an unlimited amount of time.

An old proverb states that "what is worth doing at all is worth doing well." This proverb is applicable to many cases and conditions, but a blind adherence to it is liable to be a serious detriment to a person engaged in commercial work. For such a person the proverb might profitably be changed to read "what is worth doing at all is worth doing as well as the circumstances of each case require." That is, the quality of the workmanship should be suited to the

purpose to which the work is to be put, and unnecessary refinements and ornamentation that neither add to appearance nor usefulness should be omitted.

THE SCRAP HEAP.

38. Lessons From the Scrap Heap.—The final resting place of all the metallic appurtenances of the machine shop, smith shop, and boiler shop is the **scrap heap.** In this universal receptacle are found all kinds of metallic objects in all conditions, from the new special machine left on the builder's hands by some turn of fortune to that mass of metal so thickly coated with rust or grease that only a cold-chisel test will determine whether it is brass, steel, or lead. A scrap heap is a kind of shop barometer, telling in its own mute fashion of the general shop management of the place and of the use or misuse of materials in other places. A scrap heap represents employed capital, and for this reason it should be run through the cupola or furnace as soon as possible, and thus be reduced to available assets.

Many valuable lessons can be learned by an intelligent inspection of the various pieces to be found in a scrap heap. The undue weakness of compotent parts of machinery is here shown by the presence of the broken parts, and a careful inspection of the appearance of the breaks will not only show where the parts need strengthening, but, also, whether or not the break was due to an abuse of the machine. The presence of a large number of broken small tools of the same kind may safely be considered as an indication of a defect in their design, although in isolated cases, especially in shops where much unskilled labor is employed, it may indicate bad management on the part of some responsible person.

39. Patching Chipped Castings.—In the handling of heavy castings it frequently happens that chips or flakes are knocked off by accidental collisions with other work. While these may not weaken the machine appreciably, they are unsightly, and for the sake of appearances such defects

should be remedied. There are compounds on the market especially prepared for this work. The dry compound is moistened until it has the consistency of putty, and is then pressed over the defacement and allowed to harden. When once hard, it adheres firmly and may be filed precisely like iron. It then presents a metallic surface.

40. Brazing Broken Castings. — Commonly, a broken iron casting is consigned to the scrap heap, but it is possible in many cases to prevent this loss by brazing the broken parts together. This is done by using a patented brazing composition or flux called "Borafix," which is spread evenly over the fractured surfaces. These are then placed together properly, and brought to a cherry-red heat, which melts the flux. Spelter or brazing material is added, after which the piece is allowed to cool in the air. This method recommends itself in cases where the castings are not subjected to extraordinary strains and are not excessively large. The process is a comparatively new one, but it has a valuable place in the work of the shop. Castings should not, however, be repaired in this way or in any other when it will cost more to do the repairing than it would to make a new casting.

41. Repairing a Leaky Cylinder.—To repair a leaky cylinder caused by open-grained iron, make a saturated solution of hydrochloric acid and iron drillings, and pour this into the cylinder, or wash the interior of the cylinder with the solution. Next apply ammonia water, and then steam or air pressure, which will drive the iron hydroxide into every pore of the cylinder walls. When dry, the cylinder will be steam-tight.

SHOP HINTS.

(PART 2.)

LUBRICANTS.

INTRODUCTION.

1. Two Uses of Lubricants.—A **lubricant** may serve for either one of two entirely different purposes, and should consequently be selected accordingly. In practice, a lubricant is used either in order to reduce the friction between two bodies, one of which moves on the other, or in order to carry away the heat generated by a cutting operation.

LUBRICANTS FOR REDUCING FRICTION.

2. Selecting a Lubricant.—A lubricant reduces friction by interposing itself in the form of a thin film, which may be considered as being composed of a large number of minute globules, between the rubbing surfaces of the moving bodies. These globules act as rollers or balls, and convert the sliding friction into a rolling friction to an extent depending on their deformation under the load they carry. The deformation of the globules of the lubricant depends on its consistency, and is greater for a thin lubricant than for a heavy thick one. For this reason a thick oil should be selected for heavy pressures, while for light pressures a thin oil may be used. The contact between the rubbing surfaces must also be duly considered in connection with the selection of a lubricant, and one used that is fluid enough to flow

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in between the surfaces. Thus, in machine tools and fine machinery, the rubbing surfaces are usually fitted very closely to each other, and hence fluid mineral oil having sufficient body to last a reasonable length of time must generally be used.

3. Oil for General Shop Use.—For general shop use, a mineral oil having considerable body is well adapted. It should be thin enough to run freely through the oil holes and oil channels of bearings. Animal oils are generally objected to on account of the fact that decomposition by age is liable to develop fatty acids that attack most metals. Furthermore, animal oils are very liable to gum, i. e., some of their constituent parts will collect into a sticky mass and close the oil channels of bearings. All oil intended for lubrication should be entirely free from grit. By examining a drop of the oil with a strong magnifying glass, its presence is readily discovered.

4. Cylinder Oil.—A special grade of heavy oil known to the trade as **cylinder oil,** is intended to be used for the lubrication of parts subjected to fairly high temperatures, as the valves and pistons of steam engines. It has the property of standing considerable heating without volatilizing or being decomposed. Owing to its heavy body, it is used sometimes for bearings subjected to heavy pressures.

5. Grease.—For very heavy work and relatively low rubbing speeds, one of the many forms of manufactured grease is frequently used. The bearings must then be fitted loosely enough to admit the grease. The great body, which is the characteristic feature of a grease, prevents its being crushed or squeezed out by the weight of the moving parts.

6. Grease for Ball Bearings.—Grease of the best quality may be used to advantage in putting ball-bearing work together, when difficulty is experienced in keeping the balls in place while assembling the bearing. The ball races, or seats, are filled with the grease and the balls are then pressed into it. The grease will hold the balls in place while

the parts are being put together, and will serve to lubricate them for a long time afterwards. This is a very convenient aid in assembling the ball bearings of the pneumatic drilling machines now so commonly used in large shops, and also of bicycles.

7. Grease for Shafting.— Bearings of shaftings and machines that are subject to great wear and are not at all times under the eye of the attendant, or easily within reach, and hence are liable to run dry with the ordinary methods of oiling, are provided for in the following manner: Grease cups are screwed, or grease pockets are cast, on places where bearings are liable to heat; these are filled with a grease that will not melt at the ordinary temperature of the bearing, but as the bearing becomes warm, this grease melts and runs down through the oil holes to the surfaces needing lubrication.

8. Light Oils for Cleaning Bearings.— Refined petroleum (also called **kerosene, coal oil,** or **paraffin oil,** in different localities) and **mineral sperm oil** are among the most fluid commercial oils, and will flow into smaller spaces than heavier oils; both have the disadvantage, however, that they lack body, i. e., they evaporate quickly, and consequently are of little value as a lubricant. They are of great value however in cleaning rubbing surfaces, as they will dissolve or thin down almost any heavier oil, and can be used for cleaning bearings, etc., where it is suspected that the oil channels have become clogged by the gumming of the regular oil that is used. In such a case, a copious and constant supply of kerosene or mineral sperm oil may be applied to the bearing until the oil comes out clear; it must then immediately be followed by a copious application of the heavier oil generally used for lubrication, in order to prevent any cutting of the rubbing surfaces owing to their becoming dry through the rapid evaporation of the light oil.

9. Thinning Oils.—The lighter oils can often be used advantageously for thinning down the heavier oils in order to make a grade suitable for some special purpose. Most of

the lighter oils are quite inflammable, and consequently due care must be taken to prevent their ignition.

10. Volatile Oils.—Benzine, naphtha, and **turpentine** are used considerably in shops for cleaning purposes; these oils evaporate very rapidly and form vapors that are highly inflammable. If these vapors are mixed with air in certain proportions, they form explosive mixtures that need but a spark to ignite them. For this reason, great care should be taken not to have a naked light or any fire close to a place where any of these volatile oils are stored or used.

11. Graphite.—The mineral substance known technically as **graphite,** and in shop parlance as **black lead,** or **plumbago,** forms an excellent lubricant, which when ground fine may be used either dry or may be mixed with some fluid lubricant or grease to a consistency considered suitable for the work. Graphite is one of the most refractory substances known; this fact makes it an invaluable lubricant for bearings subjected to high temperatures. Its lubricating qualities at all temperatures are so high that it forms a very valuable addition to almost any oil.

12. Curing Hot Bearings.—A bearing will get hot by reason of friction due to an insufficient or interrupted supply of the lubricant, or by reason of the journal fitting so closely that the lubricant cannot pass between the rubbing surfaces. The first thing to do when a bearing gets hot is to supply it with a liberal quantity of oil, repeating the application frequently until the bearing commences to cool. If the bearing becomes so hot that it smokes before it is discovered, and it is not advisable to stop the machine, water may be turned on the bearing, pouring it down the oil hole, or playing a hose on it until it is cool. When a hot bearing is discovered, the cap may be slacked back somewhat so as to allow a free circulation of the lubricant. As soon as the bearing is cool, a copious and constant supply of oil, which may have some graphite mixed with it, should be provided and the results noted. If the bearing refuses to keep cool

after this, it generally shows that the rubbing surfaces are in such a bad condition as to need refitting.

If the hot bearing is rigid, i. e., not self-adjusting to the shaft, observe if one end is hotter than the other; also test the shaft for alinement, as the heating of the bearing may not be caused by a defect in the hot box, but by the bearing next to it getting out of line, thus bringing all the load on one end of the bearing that is heating.

13. Oil Holes and Oil Channels.—Various means are provided to make sure that the lubricant reaches the place or surface it is intended to cover. In the first place, oil holes are drilled through the metal from the high side so that the oil will reach its proper place by gravity. The size of the oil holes should vary with the kind of lubricant that is to be used, drilling small holes in small work and for a fluid lubricant, and larger ones as the density of the oil and the length of the hole increase. Bearings that are not easily reached must have tubing or pipe run to them as directly as possible; this oil piping should be supplied with fittings that allow it to be easily taken down and cleaned.

14. Cutting Oil Channels.—Oil channels should be cut so as to distribute the oil over the whole length of the bearing; also, such other channels should be provided as may be needed to insure an even distribution of the lubricant. In order to insure thorough lubrication, the oil channels must have a liberal width and must be deep enough so as not to become filled too rapidly with the impurities some lubricants contain. Furthermore, the direction in which the oil channels run from the point of supply (the bottom of the oil hole) should be the same as the direction of rotation of the journal, in order that the latter may tend to draw in the oil rather than to repel it. A lubricant will not flow up hill any more than any other liquid; hence, the lubricant should always be applied at the highest point permitted by circumstances.

15. Special Methods of Oiling.—Small planers have their ways oiled by hand whenever they show any indication

of becoming dry. Large planers are usually provided with means for a constant lubrication, as, for instance, oil wells cored out in several places in the ways. These wells are filled with oil that is delivered to the ways by conical brass rollers that are pressed against the V's of the platen by springs. This method of oiling is perfect as long as reasonable care is used to prevent an accumulation of dust and dirt in the oil wells, which would finally interfere with the free action of the rollers.

16. Use of Waste. — Enough lubricant should be applied to machinery, and in the right place, to insure a thorough lubrication; and any dirty surface should be wiped off so as to keep the machine as neat as possible. Waste is generally used for this purpose; when dirty, it is often thrown on the floor or into out-of-the-way places; or it is left lying on the work or machine. This is an extremely bad practice, being not only wasteful and dirty, but also very dangerous on account of the liability of the waste to take fire either from spontaneous combustion or otherwise.

17. Disposition of Greasy Waste.—All waste or greasy material of this sort should be put into sheet-iron tanks or barrels located at convenient points throughout the shop. These tanks should be made of heavy galvanized iron or steel, and should have legs to keep their bottoms 2 or 3 inches above the floor. They should be riveted together, instead of being soldered, so that if the material in them does get on fire, they will not come apart and set fire to the building. A good tight-fitting cover should be kept on the tank at all times, so that if fire does start in the waste, it will be smothered before gaining much headway. These tanks should be taken out and emptied at stated times.

In some shops the dirty waste is washed and used again. The cleaning is done by putting it into a tank of water with soda, cheap soap, or some washing compound, and boiling it for a few hours by either live or exhaust steam entering the tank through a suitably arranged pipe.

LUBRICANTS FOR CARRYING AWAY HEAT.

18. Reason for Removing Heat Generated.—The cutting speed of a tool may often be considerably increased by the application of some kind of lubricant, such as oil or water. When oil is used, it reduces the friction between the shaving and the face of the tool, and thus reduces the heating. If a sufficient quantity is used, it also carries off a great deal of the heat generated by the cutting operation and keeps the tool from getting as hot as it otherwise would; consequently, it is possible to increase the cutting speed without overheating the cutting edge.

19. Lubricants for Steel and Wrought Iron. The best lubricants for cutting steel or wrought iron are the best grades of lard oil and sperm oil. One of these oils should be used for all tapping or reaming operations. For turning shafts, soda water is used, or in some cases a mixture of soft soap and water. Soda water is an excellent medium for absorbing heat; the soda also keeps the water from rusting the machines or the work. Soft soap dissolved in water is used in some shops instead of soda water and possesses some lubricating quality. When a finishing cut is taken on soft iron or steel with a keen tool, and a supply of water is kept on the tool, a very bright smooth surface is produced. Such a cut is called a *water cut;* some kinds of work are thus finished with sufficient smoothness to make polishing unnecessary.

20. Conditions Under Which Lubricants Should Not Be Used.—Cast iron is usually worked dry. The dirt caused by mixing fine cast-iron turnings with oil or water on the machine is an objectionable feature that more than overbalances the increased cutting speed that might be obtained. Furthermore, it is difficult to take a light cut on cast iron when it is oily. The oil soaks into the surface of the iron for a short distance and seems to form a skin that is not easily broken. If the cut is deeper than a finishing cut, the oil on the surface will not impede the cutting. Brass, copper, and Babbitt metal are generally cut without a lubricant,

although it is becoming the practice to flood work composed of these metals with lard oil in automatic screw-machine work so as to reduce friction and increase the life of the tools.

21. A Cheap Lubricant for Tools.—For some classes of work, a cheap and satisfactory lubricant may be made by combining oil with other ingredients. There are many such mixtures in use in which an oil is first thinned down by mixing it with a cheap liquid-like soda water, and then adding some ingredient that will give body to the lubricant, i. e., thicken it enough to make it somewhat adhesive. A good mixture may be made by mixing together ¼ pound of sal soda, ½ pint of lard oil, ½ pint of soft soap, and enough water to make 10 quarts. This should be boiled ½ hour and well stirred. When cool, it is ready for use. This mixture can easily be handled by a pump, and is quite satisfactory for general use.

22. A Pipe System of Lubrication.—When a large number of machine tools are kept busy on work where constant lubrication is deemed essential, it is often convenient to place the tank containing the lubricant in some warm out-of-the-way place, as in the boiler room. A system of piping having branch pipes leading to the different machines may then be laid through the shops. A force pump of some kind should be placed near the tank and have its suction pipe connected to it, while its discharge pipe connects with the pipe system. All the drippings may be automatically returned to another tank near the first through a separate pipe system so arranged that they will flow back by gravity. By grouping together all the machines requiring lubrication, the piping system can be made relatively inexpensive. The placing of the tank in the boiler room is especially convenient in the case of mixtures that require boiling, since a steam coil can then be placed in the tank at small expense.

Another arrangement of the pipe system has the supply tank located at a height that will cause the lubricant to flow to the machines by gravity, and the pump is used to raise it

from the lower to the upper tank. The oil should always pass through a strainer or a filter before being used again.

23. Lubricants in Cutting Babbitt Metal.—Babbitt metal may be worked dry in most cases, but when bushings of this material are being bored in the lathe or when boxes are machined in position, it is often found that a lubricant is necessary. This is especially true of bushings that are being bored in the lathe, since the chip has a tendency to wind around the boring tool and form a compact ball. Boxes that have been bored and are to be reamed will sometimes be scored or roughened in the reaming if the work is done dry. Lard oil is sometimes used in working Babbitt metal, but a copious supply of kerosene oil will give far better results than any other lubricant.

24. Lubricants for Drilling Rawhide.—It is sometimes necessary to drill rawhide with a twist drill; this, in general, will be found a trying and tedious job, on account of the clogging up of the flutes of the drill when the drilling is done dry. If a cake of ordinary laundry soap is held against the drill every little while, however, no trouble will be experienced. The drill should be run quite fast for drilling rawhide.

25. Turpentine as a Lubricant.—It is sometimes necessary for fitters who are working on cast-iron work to use a lubricant, other than the marking material, when they are rubbing two parts together in order to obtain bearing marks. Oil will prevent the seizing and cutting of the surfaces, but it will leave no bearing marks, and, besides, it will interfere with the scraping. Turpentine may be used freely on such work, however, instead of oil, and will prove beneficial rather than otherwise.

PREVENTING WASTE OF LUBRICANTS.

26. The Oil Separator.—Shops in which a great deal of screw-machine work, milling, and tapping of wrought iron or steel is done, use correspondingly large quantities of

oil to lubricate the cutting tools. This oil becomes mixed with the cuttings or chips from the work, and while most of this oil can be drained off, a large amount adheres firmly to the chips and is usually thrown away. Much of this oil may be saved by collecting the oily chips, and running them through a centrifugal separator. This **separator** consists of a circular tank that is open at the top and is provided with a cock in the bottom, in order to allow the extracted oil to be drained off. A vertical spindle passing up through the center of the tank carries a strong conical steel pan provided with an equally strong cover that is held on, when in use, by a locknut. The edge of the pan has small openings for the escape of the oil. A pulley is provided on the lower end of the spindle to drive the extracting pan, and is belted to an overhead countershaft.

The pan is filled with the oily chips, the cover securely fastened, and the machine started slowly and allowed to come up to its full speed, which should give about 7,000 feet per minute at the periphery. The oil is thrown from the chips by the centrifugal force and finds its way out through the small openings in the top edge of the pan. As the oil flies from the pan it is caught by the wall of the tank and flows down to the oil well.

27. The Oil Filter.—Oil that has been used over a number of times is liable to be filled with very fine chips that separators will fail to remove. Such oil may be filtered through a regular **oil filter**; in the absence of such a device, blotting paper will be a fair substitute. Some of the heavier particles of metal in the oil can be gotten rid of by letting the oil stand in a quiet place for some time, when the heavy foreign matter will settle to the bottom of the vessel. The clear oil may then be poured off into another vessel. This settling process will fail to clean the oil as effectually as an oil filter will do. Oil cleaned by the settling process should never be used for lubricating bearings, but only for the cutting tools. An oil filter or settling tank will not work well if kept in a cold place.

TRANSMISSION OF POWER.

BELTING AND SHAFTING.

BELTING.

28. Length of Belts.—One of the most common calculations in shop work is that concerning the length of belt that is required for a certain position. If the shafts and pulleys are already in place, the simplest way to find the necessary length is to stretch a tape line around the pulleys in the position in which it is desired to place the belt and thus to obtain the length directly. In such a case, the stretch of the tape line is taken to be the same as that necessary for the belt.

However, in case the pulleys are not in position, so that a tape line cannot be used, the length of the belt must be calculated, and this can be done by the following rule:

Rule.—*To find the length of a direct open belt, multiply one-half the sum of the pulley diameters by* $3\frac{1}{4}$ *and add to this product twice the distance between the centers of the shafts. This sum will be the approximate length of the belt required.*

The above rule, expressed as a formula, would read

$$B = 3\tfrac{1}{4}\left(\frac{D+d}{2}\right) + 2L,$$

in which B = length of belt in inches;
D = diameter of one pulley in inches;
d = diameter of other pulley in inches;
L = distance between centers of shafts in inches.

EXAMPLE.—The distance between the centers of two shafts is 10 feet; the diameter of the larger pulley is 36 inches and of the smaller pulley 28 inches. What is the length of belt required?

SOLUTION.—The distance between shaft centers is 10 ft., or $12 \times 10 = 120$ in. Then, by the rule given,

$$B = 3\tfrac{1}{4}\left(\frac{36+28}{2}\right) + 2 \times 120 = 3\tfrac{1}{4} \times 32 + 2 \times 120 = 344 \text{ in. Ans.}$$

29. The approximate length of a crossed belt is given by the formula

$$B = 3\tfrac{3}{8}\left(\frac{D+d}{2}\right) + 2L.$$

30. Arc of Contact.—The arc on which the belt touches the pulley is called the **arc of contact.** If it were possible for the belt to extend once completely around the pulley, the arc of contact would be 360°. If the belt touches the pulley along half of its surface, the arc of contact is 180°; if it touches the pulley along quarter of its face, the arc of contact is 90°; and similarly for any portion of surface covered by the belt on the pulley.

To find the arc of contact, stretch a string tightly over the pulleys in the position the belt is to occupy. Then take another string and wrap it once around the pulley and cut it so that the ends meet. The length of this string represents the distance around the pulley. Now take a third string and hold one end at the point where the arc of contact on the pulley begins, as shown by the string stretched over the pulleys representing the belt. Wrap this third string around the pulley alongside the string that represents the belt, to the point where the latter leaves the pulley. Cut the third string at this point. The length thus cut off is the distance covered by the belt on the pulley. Then, the arc of contact is equal to the length of this third string multiplied by 360, divided by the length of the second string, which represented the distance around the pulley.

The above rule applies to cases where the pulleys are in position. If the arc of contact is to be taken from a drawing, it can be quickly found by the use of a protractor.

31. Effective Pull.—The driving side of a belt is always under greater tension than the slack side. The difference in tension of the two sides is the force that tends to turn the driven pulley, or the **effective pull.** The tension, or pull in pounds, on the driving side of the belt is governed by three things: the effective pull, the coefficient of friction between the belt and pulley, and the length of the arc of

contact. The effective arc of contact is that on the smaller pulley.

The effective pull that may be allowed per inch of width of a single leather belt varies according to the arc of contact. Table I gives the allowable effective pull per inch of width for different arcs of contact of a single belt.

TABLE I.

ALLOWABLE EFFECTIVE BELT PULL.

Arc Covered by Belt.		Allowable Effective Pull Per Inch of Width. Pounds.
Degrees.	Fraction of Whole Face.	
90	$\frac{1}{4}$ = .250	23.0
112½	$\frac{5}{16}$ = .312	27.4
120	$\frac{1}{3}$ = .333	28.8
135	$\frac{3}{8}$ = .375	31.3
150	$\frac{5}{12}$ = .417	33.8
157½	$\frac{7}{16}$ = .437	34.9
180, or over	$\frac{1}{2}$ = .500	38.1

Table I enables one to calculate the horsepower that a given belt can transmit, or to find the width of a belt required to transmit a given horsepower. The allowable effective pull per inch of width varies greatly in practice; in some cases it is as much as 50 per cent. greater than that given in the table.

32. Horsepower.—The term **horsepower** represents a rate of doing work. If a man lifts a weight of 100 pounds vertically a distance of 1 foot, he does $100 \times 1 = 100$ foot-pounds of work. If he lifts a weight of 25 pounds a distance of 4 feet, he still does $25 \times 4 = 100$ foot-pounds of work.

One horsepower represents 33,000 foot-pounds of work done in 1 minute, or 550 foot-pounds per second. That is, if a belt has an effective pull of 55 pounds and runs at a speed of 10 feet per second, then the force of 55 pounds acts through

a distance of 10 feet each second, and the power developed is $10 \times 55 = 550$ foot-pounds per second, or 1 horsepower.

33. Belt Speed.—The speed at which the belt runs determines the horsepower transmitted. In order to find the speed of any belt use the following rule:

Rule.—*Multiply the diameter of the pulley in inches by 3.1416, and this by the number of revolutions per minute of the pulley, and divide the product by 12. The result is the speed of the belt in feet per minute.*

No allowance is made in this rule for the *slip* of the belt. All belts slip some; hence a slip of 2 per cent. is allowed in most belting problems. Belts sometimes run as slow as 1,000 feet per minute, or even slower, and a speed of 6,000 feet per minute should never be exceeded.

34. Horsepower of Belts.—In order to find the horsepower that a single leather belt under given conditions will transmit, use the following rule:

Rule.—*Find the arc of contact on the smaller pulley and from Table I obtain the corresponding effective pull. Then multiply together the effective pull, the width of the belt in inches, and the speed of the belt in feet per minute, and divide the product by 33,000.*

EXAMPLE.—A 4-inch belt runs on two pulleys 36 inches in diameter that make 200 revolutions per minute. (*a*) What is the speed of the belt? (*b*) What horsepower will it transmit?

SOLUTION.—(*a*) By Art. **33**, the speed of the belt in feet per minute is $\frac{36 \times 3.1416 \times 200}{12} = 1{,}884.96$ ft. per min. Ans.

(*b*) As the pulleys are of the same size, the arc of contact is 180°, and from Table I the pull is 38.1 lb. From Art. **34**, the horsepower is $\frac{38.1 \times 4 \times 1{,}884.96}{33{,}000} = 8.7$ H. P. Ans.

35. Width of Belts.—In case it is desired to know what width of single leather belt is required to transmit a given horsepower, the following rule may be used:

Rule.—*Multiply the horsepower to be transmitted by 33,000 and divide this product by the product of the speed in feet per*

minute and the effective pull. The result will be the width of the belt in inches.

EXAMPLE.—What width of belt would be required to transmit 16 horsepower when the belt is running at a speed of 2,000 feet per minute and has an effective pull of 38.1 pounds per inch of width?

SOLUTION.— $\frac{16 \times 33{,}000}{38.1 \times 2{,}000} = 6.9$ in. A 7-inch belt would be selected for this work. Ans.

36. Double Belts.—Double belts are made by cementing and riveting together two single belts, one upon the other. They are used to transmit powers that would strain or break a single belt. Naturally, the double belt is the stronger per inch of width. It is commonly assumed that a single belt has $\frac{7}{10}$ the strength of a double belt of equal width, because the thickness of a double belt is about $\frac{7}{10}$ that of two single belts. Then, to find the horsepower that a double leather belt will transmit, we have the following rule:

Rule.—*Multiply together the effective pull, the width of the belt in inches, and its velocity in feet per minute, and divide the product by* $\frac{7}{10}$ *of 33,000, or 23,100.*

EXAMPLE.—How many horsepower will be transmitted by a double belt, 24 inches wide, if the arc of contact on the smaller pulley is 150° and the belt runs at 2,500 feet per minute?

SOLUTION.—From Table I, the allowable effective pull is 33.8 lb., then $\frac{33.8 \times 24 \times 2{,}500}{23{,}100} = 87.8$ H. P. Ans.

37. If it is desired to find the width of a double leather belt required for a certain horsepower, use the following rule:

Rule.—*Multiply the horsepower to be transmitted by 23,100. Divide this product by the product of the velocity in feet per minute and the effective pull as found from Table I. The result is the width in inches.*

EXAMPLE.—What width of double belt would be required to transmit 160 horsepower with the belt running at 2,500 feet per minute and having an arc of contact on the smaller pulley of 150°?

SOLUTION.—From Table I, the effective pull is 33.8 lb. per inch of width; hence, $\frac{160 \times 23{,}100}{2{,}500 \times 33.8} = 43.74$ in. A 44-inch belt would be used. Ans.

SHAFTING.

38. Distance Between Bearings.—For a medium steel shaft having no pulleys whatever, and used for transmission of power only, the greatest allowable distance between adjacent bearings, for shafts up to and including 4 inches in diameter, is given by the following rule:

Rule.—*Multiply the diameter of the shaft in inches by 55 and add 55 to the product. The result is the greatest allowable distance, in inches, between adjacent bearings.*

For an iron shaft the maximum distance is somewhat less than that given by the above rule.

EXAMPLE.—What is the greatest allowable distance between bearings for a 3-inch shaft of medium steel, used only to transmit power?

SOLUTION.—According to the rule, the maximum distance is $(55 \times 3) + 55 = 220$ in., or 18 ft. 4 in. Ans.

TABLE II.

TURNED-IRON HEAD-SHAFTS, BEARINGS CLOSE TO PULLEYS.

Diameter of Shaft. Inches.	Revolutions Per Minute.						
	60	80	100	150	200	250	300
	Horsepower.						
1⅝	2.6	3.4	4.3	6.4	8.6	10.7	12.9
2	3.8	5.1	6.4	9.6	12.8	16.0	19.2
2¼	5.4	7.3	8.1	12.0	16.0	20.0	24.0
2½	7.5	10.0	12.5	18.0	25.0	31.0	37.0
2¾	10.0	13.0	16.0	24.0	32.0	40.0	48.0
3	13.0	17.0	20.0	30.0	40.0	50.0	60.0
3¼	16.0	22.0	27.0	40.0	54.0	67.0	81.0
3½	20.0	27.0	34.0	51.0	68.0	85.0	102.0
3¾	25.0	33.0	42.0	63.0	84.0	105.0	126.0
4	30.0	41.0	51.0	76.0	102.0	127.0	153.0
4¼	43.0	58.0	72.0	108.0	144.0	180.0	216.0
5	60.0	80.0	100.0	150.0	200.0	250.0	300.0
5¼	80.0	106.0	133.0	199.0	266.0	333.0	400.0

39. For a countershaft or line shaft having many pulleys, and consequently subjected to both bending and torsion due to belt pulls, the distance from bearing to bearing should be not more than 8 feet.

For a head-shaft, with a main driving pulley or gear, the bearings should be placed very near the driving wheel or wheels.

40. Horsepower and Size of Shafting.—The horsepower that a shaft of given size will safely transmit depends on its duty. If it is a plain shaft, used to transmit power from one point to another at a considerable distance, with no pulleys or gears at intermediate points, it will transmit considerably more than a shaft of the same size used as a countershaft or line shaft, loaded with pulleys, and still more than a head-shaft carrying a main driving pulley or gear.

TABLE III.

COLD-ROLLED IRON HEAD-SHAFTS, BEARINGS CLOSE TO PULLEYS.

Diameter of Shaft. Inches.	Revolutions Per Minute.						
	60	80	100	150	200	250	300
	Horsepower.						
1½	2.7	3.6	4.5	6.7	9.0	11	13
1⅝	4.3	5.6	7.1	10.6	14.2	18	21
2	6.4	8.5	10.7	16.0	21.0	26	32
2¼	9.0	12.0	15.0	23.0	30.0	38	46
2½	12.0	17.0	21.0	31.0	41.0	52	62
2¾	16.0	22.0	27.0	41.0	55.0	70	82
3	21.0	29.0	36.0	54.0	72.0	90	108
3¼	27.0	36.0	45.0	68.0	91.0	114	136
3½	34.0	45.0	57.0	86.0	114.0	142	172
3¾	42.0	56.0	70.0	105.0	140.0	174	210
4	51.0	69.0	85.0	128.0	170.0	212	256
4½	73.0	97.0	121.0	182.0	243.0	302	364

The horsepower that shafting of various sizes will safely transmit is given in Tables II, III, IV, and V.

These tables may be used to find the horsepower that a given shaft will transmit, or they may be used to find the size of shaft required to transmit a given horsepower.

TABLE IV.

TURNED-IRON LINE SHAFTING WITH BEARINGS 8 FEET APART.

Diameter of Shaft. Inches.	Revolutions Per Minute.						
	100	125	150	200	250	300	350
	Horsepower.						
1¾	6.0	7.4	8.9	11 9	14.9	17.9	20.9
1⅞	7.3	9.1	10.9	14.5	18.2	21.8	25.4
2	8.9	11.1	13.3	17.7	22.2	26.6	31.0
2⅛	10.6	13.2	15.9	21.2	26.5	31.8	37.0
2¼	12.6	15.8	19.0	25.0	31.0	38.0	44.0
2⅜	15.0	18.0	22.0	29.0	37.0	44.0	52.0
2½	17.0	21.0	26.0	34.0	43.0	52.0	60.0
2¾	23.0	29.0	34.0	46.0	58.0	69.0	81.0
3	30.0	37.0	45.0	60.0	75.0	90.0	105.0
3¼	38.0	47.0	57.0	76.0	95.0	114.0	133.0
3½	47.0	59.0	71.0	95.0	119.0	143 0	167.0
3¾	58.0	73.0	88.0	117.0	146.0	176.0	205.0
4	71.0	89.0	107.0	142.0	178.0	213.0	249.0

EXAMPLE 1.—What horsepower will be transmitted by a turned-iron line shaft 2½ inches in diameter, running at 250 revolutions per minute ?

SOLUTION.—From Table IV, for turned-iron line shafting, we find the diameter 2½ in. in the first column. Following out horizontally from 2½ until we reach the column headed 250 revolutions per minute, we find 43. Therefore, the 2½-inch shaft will transmit 43 H. P. at 250 rev. per min. Ans.

EXAMPLE 2.—Let it be required to find the horsepower of a cold-rolled head-shaft 4 inches in diameter, making 300 revolutions per minute ?

SOLUTION.—In Table III, for cold-rolled shafting, locate the diameter, 4 inches, in the first column, and follow this line horizontally to the column headed 300, where 256 is found. The 4-inch head-shaft will therefore transmit 256 H. P. at 300 rev. per min. Ans.

EXAMPLE 3.—What size of cold-rolled line shaft will be required to transmit 200 horsepower at 300 revolutions per minute?

SOLUTION.—In Table V, of cold-rolled line shafts, locate the column headed 300 rev. per min. Following down this column to the value 205 H. P., which is the nearest to 200 that is given, we find that the corresponding diameter of shaft, in the first column, is 3¼ in. Ans.

TABLE V.

COLD-ROLLED IRON LINE SHAFTING, WITH BEARINGS 8 FEET APART.

Diameter of Shaft. Inches.	Revolutions Per Minute.						
	100	125	150	200	250	300	350
	Horsepower.						
1½	6.7	8.4	10 1	13.5	16.8	20.2	23.6
1⅝	8.6	10.7	12.8	17.1	21.5	25.7	31.0
1¾	10.7	13.4	16.0	21.5	26.8	32.1	39.0
1⅞	13.2	16.5	19.7	26.4	32.9	39.5	46.0
2	16.0	20.0	24.0	32.0	40.0	48.0	56.0
2⅛	19.0	24.0	29.0	38.0	48.0	57.0	67.0
2¼	22.0	28.0	34.0	45.0	56.0	68.0	80.0
2⅜	27.0	33.0	40.0	53.0	67.0	80.0	94.0
2½	31.0	39.0	47.0	62.0	78.0	93.0	109.0
2¾	41.0	52.0	62.0	83.0	104.0	125.0	145.0
3	54.0	67.0	81.0	108 0	134.0	162.0	189.0
3¼	68.0	86.0	103.0	137.0	172.0	205.0	240.0
3½	85.0	107.0	128.0	171.0	214.0	257.0	300.0

EXAMPLE 4.—Suppose it is required to find the size of a turned-iron head-shaft capable of transmitting 200 horsepower at 200 revolutions per minute.

SOLUTION.—In Table II, for turned-iron head-shafts, locate the column headed 200 rev. per min. Following down this column to the value 200 H. P., the corresponding diameter of shaft, from the first column, is found to be 5 in. Ans.

HEAT INSULATION.

41. Lagging Steam Cylinders and Pipes.—Cylinders of steam engines and main steam connections need to be as thoroughly protected from the cold as possible, in order that the condensation of steam may be reduced to the lowest point. For this purpose the cylinder is often coated with a cement, or mortar, composed largely of asbestos. This is mixed, tempered, and applied to the cylinder in much the same manner that mortar is put on by a mason. The work is done after the supports for the lagging are in place, and the material is applied in such thickness as not to interfere with the lagging. The cylinders are generally heated by steam when this work is done, so as to dry the material.

Steam pipes for conveying live steam are protected in a variety of ways. Sometimes the pipe is surrounded with wire netting of about $\frac{3}{8}$-inch mesh, which is held some distance away from the pipe by distance pieces that are fastened to the wire netting and butt against the pipe. Non-conducting mortar is applied to this netting and pressed in on the pipe; when the pipe is outdoors, it is usually boxed in order to further protect it. If the pipe is indoors, it is often lagged to match the cylinder. Several kinds of sectional covering are made that are easily applied to such pipes, and are held in place by clamps or straps.

The object of jacketing or covering cylinders and pipes in this manner is to retain the heat, except in refrigerating machinery, where the object is to keep out the heat.

42. Cutting and Fitting Sheet Lagging.—Many steam-engine cylinders are covered with sheet-steel or Russia-iron lagging. This lagging, when possible, is cut to the right dimensions and rolled into a cylindrical form; or it is sheared to the proper dimensions, if the cylinder is to be lagged square. There still remains a great deal of fitting on the sheet, or sheets, which is generally done by hand, but which may be done on a machine similar to that illustrated in Fig. 1 (*a*). This machine has a column *a* that carries a

table *b*. A movable slide *c* working in guides formed on the column carries a cutter *d*, which is attached to the slide by the clamp *e*. The guide bar *f* has a slot in its front side in which the cutter *d* slides; it is held in position by a screw and a hand wheel *g*. The machine is driven by means of the

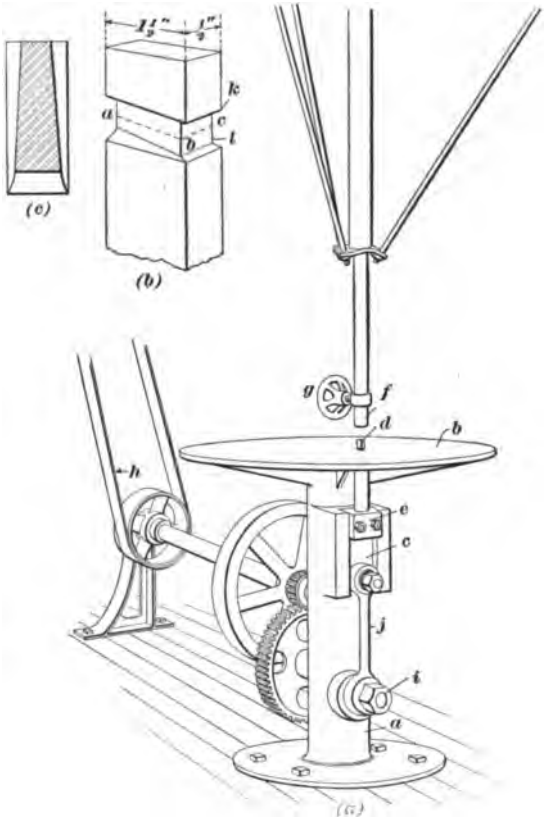


FIG. 1.

belt *h*, and an up-and-down motion is imparted to the cutter *d* by means of the crank *i* and rod *j*. Fig. 1 (*b*) is a detail of the square cutter used, in which *k* is the cutting edge. The sheets to be cut are laid on the table and pushed into the notch *l*; the cutter then shears out a chip on the

down stroke. Fig. 1 (*c*) shows a section of the cutter in the plane indicated by the lines *a*, *b*, *c*, Fig. 1 (*b*). Cutters of any section may be made for following curved lines as well as straight lines.

The lagging sheets are worked out on this machine to nearly the right form and the remainder of the fitting is done by hand. The screw holes in the sheets are generally drilled in a power-driven machine. Finally, the sheet is clamped in place while the holes are marked off on the cylinder or lagging frame; these are then drilled into the supporting surfaces on the cylinder or the lagging frame.

MISCELLANEOUS DEVICES.

43. Boxes, Pans, and Trays.—All shops and manufacturing establishments doing small work have more or less trouble in moving small parts from place to place. This is generally done by using such boxes, kegs, and barrels as happen to be at hand. These soon become dirty or are broken, and must then be replaced.

An excellent substitute for these makeshift devices is found in the metallic articles illustrated in Fig. 2. The one shown in Fig. 2 (*a*) is a steel box that can be used instead of a wooden one for many shop purposes. The pressed-steel pan illustrated in Fig. 2 (*b*) may be used instead of the box, and has the advantage that it will hold water or oil. These pans, when not in use, may be stacked up, so as to occupy very little space. These boxes are commonly called **tote boxes.**

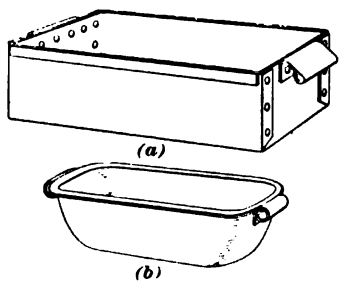


FIG. 2.

Another useful and cleanly device is the **tray rack,** illustrated in Fig. 3. It consists of three iron trays, the

upper one of which carries a drawer. For shop use, casters are added so that it may be moved from place to place. It is especially useful where a number of operations have to be performed on pieces by different machines. The trays may be used by the machine-tool man to hold both his tools and work, while the drawer may contain his individual tools.



FIG. 8.

44. Keeping Machine-Shop Tools.—Various methods are followed in caring for machine-shop tools. In the simplest method, the tools are thrown down where used and left there until they are wanted for another job, when they are hunted for until found, and are then cleaned and again made ready for use. This method is probably the worst that could possibly be devised, and is a direct evidence of mismanagement. The modern and proper plan of caring for tools is to require all tools to be cleaned by the user, and to be returned to such a place as may be designated for their storage and care.

Tool rooms are built in most shops for the storage and care of all the tools used in the place, or, if the shop is divided into departments, each head of a department may have his own tool room and a man to care for it, who, in addition, also does such other work as he may have time for. The tool room may be used only as a storeroom for tools, or it may be equipped with such a varied selection of machine tools that any tool or appliance needed on the work may be made there, and tools and light machinery may be repaired.

Large shops usually have, in addition to the tool room, such storerooms or vaults as may be needed for the storage of any large and valuable jigs, tools, or fixtures that are seldom needed, but that require protection from fire. Tools should be kept in such a manner that they may be gotten out and returned in the least time, and should also, while in their places, be as well protected from dust and rust as possible.

Drawers are extensively used for holding tools, and for many purposes they answer admirably. They are, however, very liable to be overloaded, which soon racks them to pieces. This may be avoided by making them extra heavy, or providing rollers for them to run on. They may also be easily handled if the sliding surfaces are of hard wood or are metal-faced, and the contact surfaces greased occasionally with a good lubricating grease. Drawers are used to the best advantage for tools that are seldom needed, but require protection from injury and dirt.

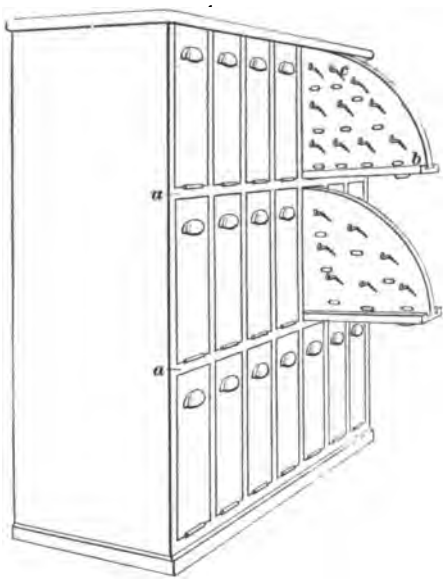


FIG. 4.

Shelves or pigeonholes furnish the most ready means of keeping tools that are much used. These should be as shallow as possible in order that the tools may not be pushed in out of sight, and that they may be easily brushed out, or blown out if an air hose is used for cleaning. Cupboards containing numerous shelves are useful for special tools that are used less frequently than standard ones, since the cupboard doors protect them from dirt and the atmosphere.

The walls of tool storerooms are often covered with boards, which should be painted and have hard-wood pegs put into them on which to hang milling cutters and similar tools; in some cases, nails are used instead of the wooden pegs. A better method of keeping cutters is shown in Fig. 4, which consists of a cabinet having a series of shelves *a* to which boards *b* are hinged. These boards are provided with hooks *c* on which to hang the cutters. This cabinet provides a clean, convenient, and space-economizing place for a large number of milling cutters and gear-cutters.

Racks of various kinds furnish a convenient and clean place for keeping a large class of tools, such as pipe stocks, wrenches, long taps, reamers, drills, boring bars, cutter bars, sockets, and other similar long tools, in such a manner that they are easily put away or gotten out, and are kept clean when in their places. A rack of this description is shown in Fig. 5. It consists of four uprights *a* that are braced by wrought-iron tie-bars *b*. These are held by long bolts *c*, which pass through the tie-bars *b* at each end, and are surrounded by distance pieces *d* made of iron pipe.

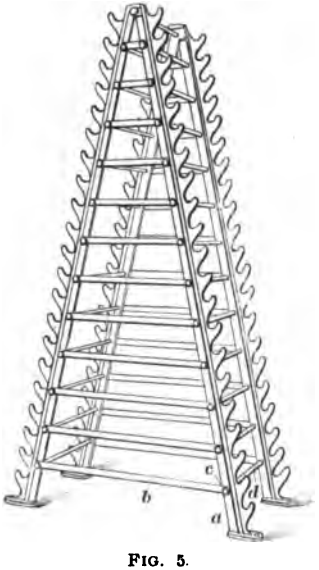


FIG. 5.

Racks that are constructed in the manner shown in Fig. 5 may be made 7 feet high and 3½ feet wide at the base, with the upright spaced at such distances as will accommodate the shortest tools that may be kept on them. Light and frequently used tools are piled on the arms, while less used and heavier tools are placed on the cross-pieces *b*. These racks may stand against the wall, but are preferably placed on the floor where they can be reached from all sides. Racks of special design are usually provided

for such tools as ratchets, tapping attachments, air drills, and other portable drilling and grinding fixtures. Boxes are sometimes used for storing tools, and when so used they should be plainly marked; a convenient record should also be kept of their exact contents.

45. The Ram.—It is sometimes necessary when taking old machinery apart, as, for instance, when trying to remove an old shaft from a wheel or crank, to strike the heaviest blow possible. The heavy blow carries the object struck before it, while lighter blows will simply upset the end of the piece and thus rivet it into place. When heavy sledge hammers are used on light work, the surfaces hammered should be protected by a piece of Babbitt metal or copper held or laid on them.

Where heavier blows are required than can be struck with a sledge, a **ram** is used. This is a long bar of iron suspended at its center of gravity, in order that it may hang in a horizontal position, and hung in front of the piece to be rammed. The rope suspending the ram is made fast to an overhead point, after which the operators draw the bar, or ram, backwards as far as possible, and then run with it toward the piece to be struck. The ram is often used when a hydraulic press is not available or would be unfit for the work. Care should be taken in using the ram not to upset the face of the part that is being rammed, which will only tighten the parts in their places.

Since several men are required to operate a heavy ram, it is an expensive operation that should not be resorted to if a press can be used.

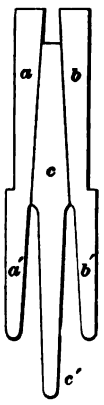


FIG. 6.

46. A Sectional Key.—In shrinking together two pieces that have key seats that must be in line with each other, a device known as a **sectional key** may be advantageously used for alining the pieces. One form of this device is shown in Fig. 6. Two tapered side keys *a* and *b*, having handles *a'* and *b'* of suitable length, are placed into

the two key seats of the two parts that are being shrunk together; and when these parts are in place, a tapered centered key c, with a long handle c', is then driven in between them, thus forcing the side keys against the sides of the key seats and alining them. When the work has cooled off, the device is removed, and the permanent key fitted and driven home.

BABBITT METAL AND BABBITTING.

BABBITT METAL.

47. Composition of Babbitt Metal.— Babbitt metal is an anti-friction alloy named after its originator, who used it in a form of journal-box that he invented. Babbitt metal is composed of tin, copper, and antimony. The proportions of these elements as originally used are given by the best authorities as follows: For heavy duty, 50 parts tin, 2 parts copper, 8 parts antimony; or, 96 parts tin, 4 parts copper, 8 parts antimony; and for light duty, 50 parts tin, 1 part copper, 5 parts antimony.

The term Babbitt metal is also applied to a great number of alloys on the market that are used to line journal-boxes. If the user wishes to insure himself against the purchase of worthless imitations, he should either make the Babbitt himself or have it made after correct specifications by a reliable manufacturer.

The melting points of these three metals may be taken as follows: Copper, 1,930° F.; antimony, 1,000° F.; tin, 445° F.

48. Making Babbitt Metal.— In making Babbitt metal, it is necessary to melt the copper first, as its fusing point is higher than that of either of the other two elements of the compound. Add the antimony to the melted copper, and then put in about one-third of the tin. The copper should be covered with a layer of powdered charcoal, to prevent oxidation and vaporization of the tin and antimony. Keep

the mass well stirred with a dry pine stick; add the remainder of the tin, and cast into small ingots. These usually vary in weight from 1 pound to 10 pounds, depending on the quantity to be used on the work.

It does not necessarily follow that genuine Babbitt metal is required for all such work. In fact, it should not be used in boxes for all speeds and pressures. The legitimate cost of anti-friction linings for journal-boxes will vary, of course, with the prices of their constituent elements, and this cost should be proportioned according to the needs of the case.

From the standpoint of cheapness, ease in handling, anti-friction properties, etc., lead would be ideal as a bearing metal. For this reason it forms the basis of a great number of the alloys used for lining journal-boxes, in which other metals, such as antimony, copper, tin, and zinc, are added to correct the softness and the shrinkage of the pure lead.

In melting Babbitt, care must be taken to heat it slowly. Cover the surface of the melting metal with powdered charcoal, to prevent oxidation of the tin and antimony, and stir with a dry pine stick. This stick serves as a guide to the correct temperature of the Babbitt, since the molten metal must not become so hot as to char the pine.

49. Old type metal makes an excellent bearing metal for ordinary work, in fact all except heavy work, and for light work it will carry some additional lead. In one case the back pillow-block of a 60-horsepower engine babbitted with type metal, when taken out after 25 years' use, showed little or no signs of wear.

BABBITTING.

50. Melting Babbitt Metal.—Babbitting is not considered fine work, but at the same time it requires considerable experience and skill in order to do it well. The amount of babbitting done in a shop varies. An occasional box can be babbitted by metal melted in an iron ladle over a blacksmith's fire, but in larger establishments the steady

employment of several men with special fires and appliances are often required. Babbitt metal should never be melted over a blacksmith's fire that is to be used for welding, for if a little of it gets into the fire, it is likely to spoil the welds. Therefore, it is well to have a fire set apart for melting Babbitt. A portable forge is especially useful for this work, as it can be moved to the place where the work is to be done. Coke is preferable to coal for melting Babbitt on account of the fact that it makes less smoke. Natural gas is an excellent fuel for this purpose. The ladles may be either of wrought iron, steel, or cast iron, and should be discarded when worn thin in the bottom, as metal may be lost by an unnoticed leak. For large work, the melting is usually done in either a cast-iron kettle or a boiler-iron ladle set in a brick furnace. The surface of the metal when melting should be covered with powdered charcoal to exclude the air in order to prevent excessive oxidization. The melted metal is dipped out of the melting pot in hand ladles, from which it is poured into the boxes. Care should be taken to heat the ladles so that they may not chill the metal. A little powdered rosin should be scattered on the surface of the metal and the metal stirred with a stick just before pouring. The rosin acts as a flux and leaves the metal cleaner and more fluid.

51. Form of Box for Babbitting.— The Babbitt metal in boxes or bearings is generally held in place by raised strips or projections cast in the box, which enclose it on all sides, for the purpose of restraining the tendency of the metal to stretch or flow under the pressure or pounding of the shaft. The strips should be cut below the surface of the bearing, so as not to come in contact with the journal. In the case of large boxes, dovetail grooves are sometimes cast in the surface of the casting to aid the strips in holding the Babbitt, and in some cases the strips are omitted, and the dovetail grooves only are relied on to hold the metal. Important journal-boxes like those in the pillow blocks of an engine are generally babbitted from $\frac{1}{8}$ to $\frac{1}{4}$ inch smaller than the finished bore. The metal is then hammered into the

box by using the round peen of a hammer to either compress or expand it firmly into place, after which the journal is bored to the required diameter.

Roller tools such as are used for expanding copper linings into pump and hydraulic cylinders, as illustrated in Fig. 7, may be used to advantage for expanding Babbitt into place. If the Babbitt bearing is chucked in a lathe, the tool (*a*) is used in the tool post and fed through the work after the manner of a boring tool; or, if a boring bar is used, the tool (*b*) may be inserted in the bar or cutter head and takes the place of a boring tool. The feed and speed of the roll may be considerably faster than in the case of a boring tool. The surface to be rolled may be lubricated with soda or soap, water or oil. In the case of small bearings, the metal is compressed by driving or forcing one or more polished steel drift plugs through the bearing.

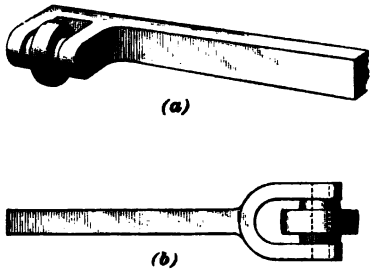


FIG. 7.

52. Mandrels for Babbitting.—A mandrel of the same, or approximately of the same diameter as the shaft for which the box is made, is placed in the box when the Babbitt is poured. The mandrels are often made hollow, as shown in Fig. 8, and consist of a cylindrical portion *a* with a bar *b* across each end. The bars *b* carry the centers *c* for turning the mandrel in a lathe. The hollow mandrel is not only cheaper than a solid one, but is also lighter to handle and quicker to heat in case it is desired to warm it before pouring the Babbitt. Mandrels are also made of wood. Iron mandrels should always be warmed before the metal is poured into the box.

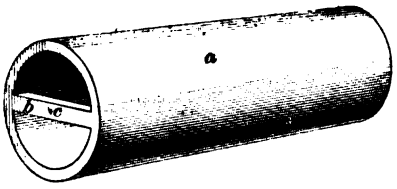


FIG. 8.

The mandrels are often made a little larger than the journal that is to be used in the box, both to allow for the shrinkage of the box and to insure that the bearing will not bind the shaft sidewise; a box that bears in the bottom is less likely to heat than one that pinches the shaft sidewise. Sometimes paper is wrapped about the journal, which is used instead of a mandrel; this is not advisable except in the case of temporary work.

Strips of pasteboard or wood may be placed between the mandrel and the strips that retain the Babbitt in the box to insure a proper thickness of Babbitt. To prevent the Babbitt from running out at the ends and joints of the box, the openings should be closed with clay or putty; care should be taken that they are not too wet, as water in the mold is likely to form steam and blow out the metal. A pouring basin leading to the box may also be made of clay or putty; large boxes are sometimes poured from several ladles simultaneously. In all cases, ample vents should be left for the air to escape from the box, and the metal should be poured at a low heat and as rapidly as possible. The surface of the mandrel should be slightly oiled.

53. In case a large number of boxes with machined ends are to be babbitted, a mandrel of the form shown in Fig. 9 may be used and both parts of the box poured at once.

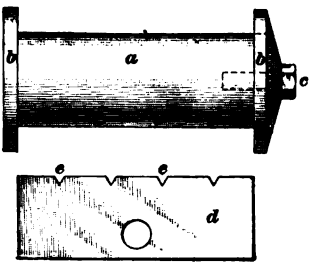


FIG. 9.

The mandrel consists of a cylinder *a* of the required diameter and length, with a disk *b* at each end to fit against the machined ends of the box. One disk is held in place by a cap screw *c* and is removable. The mandrel is put in position in the bottom of the box, and a liner *d* of pasteboard or sheet iron placed against each side of it and the cap bolted on. The Babbitt is poured through the oil holes or slot in the cap and reaches the lower part of the box through the

notches *e* in the liners *d* that are in contact with the sides of the mandrel *a*. The two parts of the box are separated by driving a wedge under the cap.

54. In Fig. 10 (*a*) and (*b*) is shown a rig for babbitting the pillow blocks of a center-crank engine. The engine

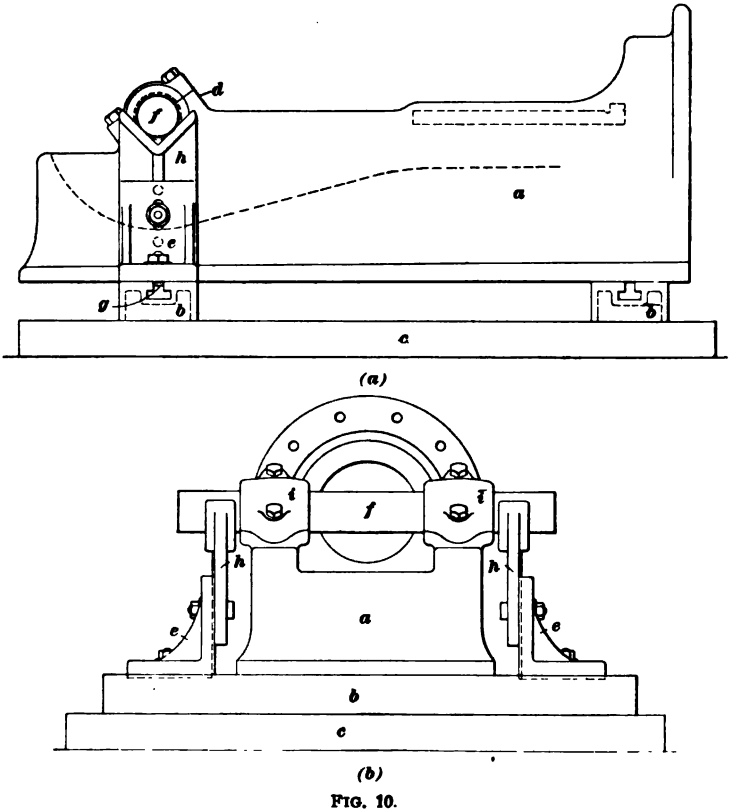


FIG. 10.

bed *a* rests on the parallels *b*, *b*, which are supported by a cast-iron floor plate *c*. The parallel *b* under the pillow-block *d* is set square across the plate *c* and bolted to it, and the engine frame *a* is set to a center line on the plate *c*. A standard *e* rests on the cross-bar *b* under each end of the engine shaft *f*. The bottom of the standard *e* has a

projection *g*, that fits in the groove in the bar *b*, and a bracket *h* with vertical adjustment is bolted to the top of the bracket and has a V-shaped top that embraces and supports the shaft of the engine or a mandrel *f*; when the mandrel is properly adjusted, the Babbitt is poured in the two boxes *i*, *i*.

55. A more elaborate fixture for holding the mandrel, and one that is self-centering, is shown in Fig. 11. The

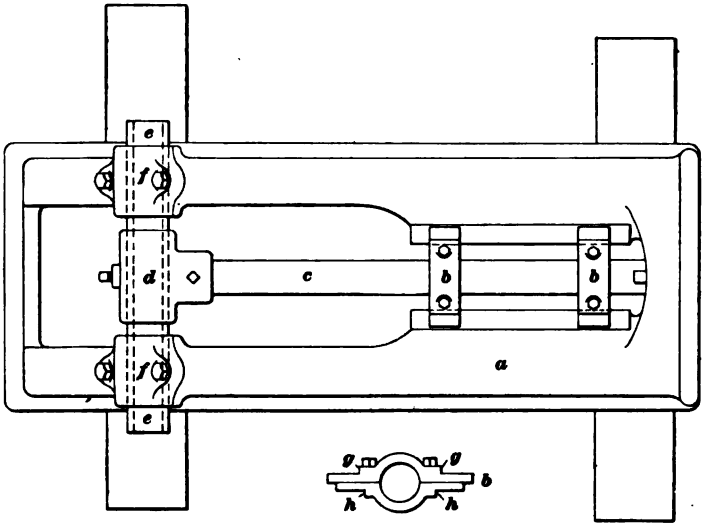


FIG. 11.

lower guide bars on the engine bed *a* having been planed, a fixture shown at *b* is placed at each end of the engine guides and these support a bar *c* with a casting *d* on the end to hold the babbitting mandrel *e*.

Different sized boxes may be babbitted by having several mandrels all the same size in the center *d*, but of smaller diameter in the journals *f*, *f*. The center of the hole in *d* for holding the mandrel *e* can be bored, if desired, $\frac{1}{8}$ inch or so higher than the center of the hole for the bar *c*. This will allow for the spring of the bar *c* and also bring the center of the journals a little above the center line of the engine, so that the first wear will be down toward the center line

and not away from it. Keys may be fitted in the shaft *c* and the castings *b* and *d* to level the mandrel *e*, or the keys may be omitted and the mandrel *e* leveled by a surface gauge on the floor plate under the engine bed, or a spirit level may be used on the mandrel *e*. The rig shown in Fig. 11 can be made to serve for babbitting two sizes of engine by making the casting *b* with two sets of shoulders *g*, *g* and *h*, *h* to fit the guides of two sizes of engine.

56. When a large number of engines are to be built, a babbitting jig may be made for each size, as shown in Fig. 12, which is a single casting *a* with a rib *b* to stiffen it.

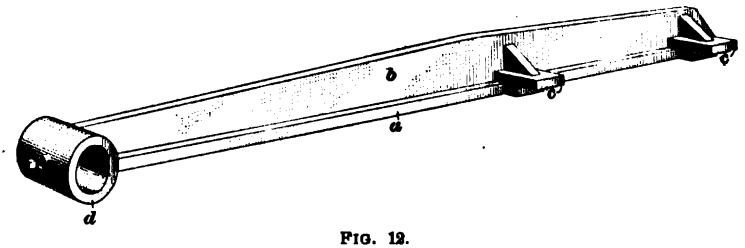


FIG. 12.

The casting is planed under the lugs *c*, *c* to fit the engine guides and bored at the end *d* so as to receive and support the babbitting mandrel. Many other forms of mandrels may be designed to meet the requirements of the case in hand.

57. Rebabbitting a Box.—In case a babbitted box is so worn down as to require renewal, first chip out the old Babbitt metal and then proceed to rebabbitt as nearly in the way described for a new box as the appliances at hand will permit.

58. Babbitting Journal Brasses. — Journal-box brasses are sometimes lined with Babbitt metal. It is necessary to tin the surface of the brass so that the Babbitt will adhere to it. The surface must first be made bright and clean by machining, grinding, or pickling; it is then heated a little above the melting point of tin, 445° F., moistened with tinning solution, and a stick of tin rubbed on the surface. The tinning solution is made by dissolving zinc in

muriatic acid; sometimes sal ammoniac is added. Tinning salts are also on the market. After the surface is thoroughly tinned, the Babbitt is poured in the usual way, but in this case unites with the tin and is held firmly to the brass.

59. A special mandrel for babbitting brasses is shown in Fig. 13. The mandrel consists of a hollow cast-iron cylinder *a* resting on a base *b* bolted to a table *c*. The cylinder *a* is turned to the proper diameter to fit the brasses *d*, and has two lugs *e*, *e* for the edges of the brasses to rest against, leaving a space *f* between the mandrel and the surface of the brass that is to be filled with Babbitt. The brass *d* stands on the base *b* and is held against the lugs *e*, *e* of the mandrel *a* by means of a curved lever *g* hinged to the frame at *h*. The Babbitt is poured from a dipper into the space *f*, and the brass is removed as soon as the metal sets. The cast-iron mandrel *a* is cooled by means of a circulation of water that enters through a pipe *i* attached to the center at the bottom.

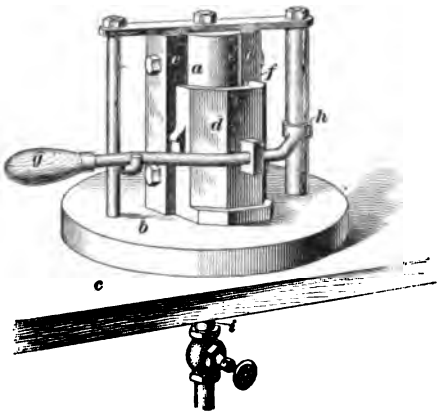


FIG. 13.

USEFUL INFORMATION.

60. Putting in Wood Screws.—The machinist is sometimes obliged to put in wood screws. These can be screwed home easier if they are rubbed with, or stuck into, a cake of tallow, while in the absence of tallow any heavy grease or oil may be used. Screws that are thus lubricated may be easily taken out again. Wood screws may be put into the hardest wood by the following process: A screw of

the size to be used is filed or ground to the form of a half-round bit, thus making a tap of it. A hole, equal in diameter to the size of the screw at the bottom of the thread, is drilled or bored into the wood and the half-round tap is screwed in. This cuts a good thread into which the screw, which should be well greased, may be easily screwed.

61. Cutting Soft Rubber.—Soft rubber is very hard to cut smoothly, even when the knife is very sharp. It can be cut quite easily, however, if the knife, which must be sharp, is dipped frequently into water, or wet with saliva.

62. Working Vulcanized Rubber. — Vulcanized rubber, which is more frequently called hard rubber, is a material that is hard to machine smoothly on account of the fact that it dulls the tool very rapidly. The tool used for turning or planing it may be a little keener than that used for steel, and should be left just as hard as fire and water can make it. Hard rubber can be machined to the best advantage with a diamond-tipped tool. Vulcanized rubber will take a high finish, which is obtained by buffing it on an ordinary buffing wheel.

63. Bluing Iron and Steel.—Polished work made of iron or steel may be given a beautiful blue color by heating it in hot sand, in wood ashes, or in pulverized charcoal. The substance in which the article is to be blued may be put into an iron kettle that is placed over a fire. The substance must be constantly stirred while it is being heated in order that the whole of it may be brought to an even temperature. The article or articles to be blued must be absolutely free from grease if an even color is desired; they may be placed into a wire basket or may be suspended by wires and then immersed in the heated substance until the desired color is obtained. A light-blue color can be obtained by heating in sand or wood ashes, but a dark-blue color requires the article to be heated in pulverized charcoal. The brightness of the color depends largely on the finish; the higher the polish upon the work, the more brilliant the color which will be obtained. The substance in which the

heating is done should be just hot enough to char a dry pine stick. By this manner of bluing, a piece of work having thick and thin parts can be given an even color all over.

64. Blacking Iron and Steel.—Polished articles of iron and steel can be given a deep lustrous black color by immersing them into a heated mixture composed of 1 part of black oxide of manganese and 10 parts of saltpeter, by weight. This mixture should be heated in an iron kettle until it is hot enough to char a pine stick. The articles to be blackened must be scrupulously clean; the excellence of the color will depend on the degree of finish of the work.

When bluing or blacking articles in a heated substance, it must be remembered that the articles will themselves become heated, and that if they are hardened, the temper will be drawn.

65. Browning Iron and Steel Chemically.—Many articles of iron and steel can be given a color varying from a light brown to a deep black by a chemical treatment. For this purpose a solution composed of 1 part of corrosive sublimate dissolved in a mixture of 16 parts of sweet spirits of niter and 16 parts of alcohol, by weight, is used. The article to be browned is cleaned thoroughly, so as to be free from grease, and is then washed with wet lime, and finally rubbed down with dry lime, in order to eliminate all traces of grease, as the success of the treatment depends on it. Care must also be taken not to touch the article with the fingers after it has been cleaned, by fitting wooden handles to it by which it can be held. The article having been cleaned, the browning solution is applied with a sponge and the article is put in a dark, dry place until a dry rust has formed on it. This will take from 8 to 48 hours, depending on the condition of the weather and the hardness of the material. When the rust has become dry enough to fly when a file card is applied to it, the article is carded off with a card that must be absolutely free from grease; it will now be found to have a light-yellow color. Another coat of the browning solution is now applied and after the dry rust has

TABLE VI.

CAPSCREW HEADS.

Diam of Screw.	Hexagonal Head.		Round Head.		Fillister Head.		Button Head.		Flat Head.*	
	Diam.	Height.	Diam	Height.	Diam.	Height.	Diam.	Height.	Diam.	Height.
$\frac{1}{5}$			$\frac{3}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{7}{32}$ full†		$\frac{1}{4}$	
$\frac{3}{16}$			$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{5}{16}$		$\frac{3}{8}$	
$\frac{1}{4}$	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{7}{16}$		$\frac{15}{32}$	
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{9}{16}$		$\frac{5}{8}$	
$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{5}{8}$		$\frac{3}{4}$	
$\frac{7}{16}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{3}{4}$		$\frac{13}{16}$	
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{13}{16}$		$\frac{7}{8}$	
$\frac{9}{16}$	$\frac{13}{16}$	$\frac{9}{16}$	$\frac{13}{16}$	$\frac{9}{16}$	$\frac{13}{16}$	$\frac{9}{16}$	$\frac{15}{16}$		I	
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	I		$1\frac{1}{8}$	
$\frac{3}{4}$	I	$\frac{3}{4}$	I	$\frac{3}{4}$	I	$\frac{3}{4}$	$1\frac{1}{4}$		$1\frac{3}{8}$	
$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$				
I	$1\frac{1}{4}$	I	$1\frac{1}{4}$	I	$1\frac{1}{4}$	I				
$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$								
$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$								

* The angle of the conical head of the flat or countersunk head is 72°. † No. 4 wire.

formed, the article is again carded off, when it will be found to have a dark-yellow color. The next repetition of the process will give it a light-brown color, then a dark-brown, and finally, a deep-brown. The deep-brown color is changed to a black color by immersing the article in boiling water for a few minutes. After the article has dried, and while still hot, it should be given a coat of oil and be allowed to cool slowly.

A more lasting black color can be obtained if the article is put into an oven that is heated by steam to a temperature of 300° F., and keeping it there for about 8 hours. Instead of the file card, a rotary steel-wire brush may be used to advantage when much browning is to be done. The barrels of firearms are browned by the process just described, or by modifications of it.

66. Capscrews.—It is frequently desirable to know the diameter and the length of the head of a capscrew of given form. Table VI gives these dimensions for five different forms of capscrew heads, for screws ranging from $\frac{1}{8}$ inch to $1\frac{1}{4}$ inches in diameter.

TOOLMAKING.

(PART 1.)

GENERAL TOOL-ROOM WORK.

INTRODUCTION.

1. Definition.—Toolmaking may, in general, be defined as the making of tools. A **tool** in its broadest sense may be any device, instrument, appliance, machine, or apparatus that is intended to perform some essential function in the production or transformation of raw material into a finished product or that aids in the performance of some function required for the change.

Custom, however, has narrowed this definition until the term *toolmaking* now comprises only the production of tools by the aid of which the integral parts of devices, instruments, appliances, machines, or apparatus can be formed through cutting, drawing, compressing, or abrading operations performed on bodies susceptible to these operations. The most important subdivision of toolmaking relates to the production of tools for the working of metals, and is the one that will be treated of here.

METHOD OF PROCEDURE.

2. There are several stages in the production of tools; it is rather difficult, however, to draw a distinct line of demarkation between the ending of one stage and the beginning of the other, since they frequently blend more or less together, according to the circumstances of each

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individual case. Generally speaking, these stages are as follows: *conception; commercial consideration; design;* and, finally, *construction.* The stages follow in the order named.

3. Conception of the Possibility of Improvement.—This may be considered as the foundation of progress. Ability to conceive possibilities requires not only intimate knowledge of every stage of the particular process or operation under consideration, but also full knowledge of the good points, defects, capabilities, and limitations of the tools used for this process or operation.

4. Study of the Commercial Considerations.—Will the improvement pay? This question must be asked in each and every case, and must have been answered in the affirmative before any further step is taken. Naturally, each case must be investigated by itself and decided upon its own merits. First of all, the probable cost of improvement must be estimated; the saving that the improvement will effect must then be carefully investigated. Finally, it must be determined if the ratio that the saving bears to the investment required to effect it is sufficient to warrant the expenditure. It is always to be remembered that the primary object of tool improvement is the lessening of the cost of production, or the analogous object of raising the quality of the output without increasing the selling price.

5. Design.—Since the cost of a tool depends largely on its design, and since the latter also directly determines its ultimate value, it will be apparent that the design is a very important matter. It must always be remembered that there are usually quite a number of different ways in which an object can be accomplished; then, in order that the first cost of a tool shall be within reasonable limits, it is necessary to carefully study the facilities at command. This consideration shows the importance of a thorough knowledge of tool-room operations, appliances, and special processes. For this reason, in the majority of manufacturing establishments, the design of special tools is left entirely to the toolmaker or to special designers.

When designing a tool, various ways of accomplishing the object sought will present themselves successively; unless special considerations prevent it, the design that will accomplish the object in the most direct manner is the one to be chosen. A good tool designer will never introduce complicated mechanical movements or such special modifications of relatively simple ones as are not only expensive to produce but difficult to keep in proper alinement. Simplicity, accessibility, compactness, rigidity, durability, and handiness are the prime factors requisite in a successful tool, whether it be a boring machine for boring the largest sizes of steam-engine cylinders, or a box tool for a small automatic screw machine.

6. Construction.—In the construction of tools, the toolmaker is very frequently called on to solve problems that, while not essentially different from those of the machinist, still require entirely different methods of procedure to accomplish the object sought. Thus, the problem of locating and drilling a couple of bolt holes 3 inches apart, when the bolts have a clearance of $\frac{1}{16}$ inch or more, is solved in an entirely different manner from that of producing two holes with their axes parallel and in the same plane, and 3 inches apart, within a limit of variation not to exceed $\frac{1}{10000}$ inch. In the first case, the combination of a drill press, center punch, hammer, 2-foot rule, a drill, and a laborer will usually be sufficient; in the second case, an accurate lathe kept in the best of condition, fine measuring tools, standard test gauges, an extremely sensitive indicator, and other special appliances used by a highly skilled toolmaker, will be needed to locate the holes within the given limit of variation.

In the construction of a tool, the purpose of every part of it must be taken into consideration in order to prevent undue accuracy and unnecessary expense consequent thereto. It is a mistake to accurately machine, scrape, and finish parts that may be said to "fit a hole in the air." The time needed for this can be spent more profitably on those parts that

accomplish a useful purpose; likewise, it is unnecessary and a direct waste of time to go to the utmost refinement of measurement in a gauge that may be "plenty good enough" if accurate within $\frac{1}{64}$ inch—as a gauge for the blacksmith, for instance. Before constructing a tool, the purpose and the accuracy required for each integral part of it should be studied; the operations necessary to produce it can then be regulated accordingly.

7. The design and construction of a tool are intimately correlated, as becomes painfully apparent when special methods needed for its construction have not been taken into account and it becomes necessary to devise expensive makeshifts in order that the whole work previously done on the tool may not be lost. For this reason, no matter by whom the tool has been designed, it is good practice to go over the whole design and see if every operation required in the production of the tool can be actually performed with the facilities at hand. If not, and when circumstances permit it, the design should be changed; provided, of course, that the change will not affect the efficiency.

DIMENSIONING DRAWINGS.

8. In dimensioning a drawing, it should always be the aim to give all dimensions with special reference to the manner in which the tool must be constructed. If the toolmaker will have to work from some certain surface in order to lay out the different parts of the tool, and will have to make all his measurements from it, let all dimensions on the drawing or sketch read from that surface. If this plan is followed, a great deal of needless work is obviated. When giving the distance between holes that have to be accurately located in reference to each other and in reference to some fixed point of the tool, put in *all* the dimensions that the toolmaker needs to thus locate them; this is better than expecting him to make these calculations himself.

A case in point is shown in Fig. 1. In view (*a*), part of a jig is shown in which the three holes are to be located with reference to one another and to the finished surfaces *a* and *b*, as shown by the dimensions. The dimensions given would be sufficient for work not requiring any great degree of accuracy, say for ordinary machinist's work. With these dimensions, the aid of a surface gauge, a surface plate, an angle block, and by extremely careful work, the centers may be laid out within a limit of error of $\frac{3}{1000}$ inch, and an expert may even bore the holes within that limit of variation. But suppose that a greater degree of accuracy is required; assume that the limit of variation is not to exceed one-half of $\frac{1}{1000}$ inch. In order to obtain this degree of accuracy, which must not be imagined to be anything extraordinary, the toolmaker must substitute contact measurements for measurements taken from a scale and then transferred by scribed lines to the work. In order to make these contact measurements, the toolmaker needs the dimensions marked *x*, *y*, and *z* in Fig. 1 (*b*); if these are not given, he cannot conclude the work until they are supplied.

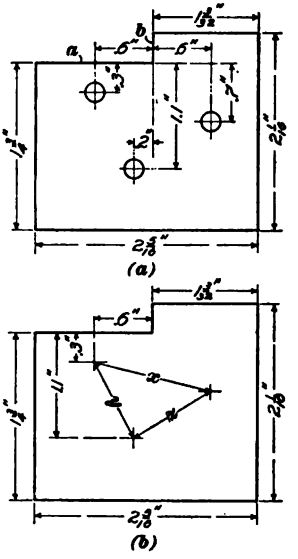


FIG. 1.

9. Referring again to Fig. 1 (*a*), it will be noticed that the dimensions locating the holes with reference to one another and to the surfaces *a* and *b* are given in decimal parts of an inch, and the other dimensions in common fractions. This is done in accordance with a method of dimensioning that, while not universal, is well deserving of wider application. It simply signifies that all dimensions given decimally are *accurate* dimensions, and that the parts are to

be located or made to those dimensions as closely as can be measured with a micrometer, vernier calipers, or similar measuring instrument decimally graduated. On the other hand, for those dimensions that are expressed in common fractions, no great accuracy in machining or fitting is required. If this system of dimensioning is adopted, it usually results in the reduction of needless accuracy, which, in turn, means a decided saving in the labor cost.

On good work it is often advisable to specify on the drawing the limit of variation permissible; this prevents choice of methods entailing a vast amount of work when less elaborate methods will produce a job that is "good enough for the purpose."

READING DECIMALS.

10. Since, with very rare exceptions, the measuring instruments of the toolmaker are graduated to read to the one-thousandth part of an inch, and some to the one ten-thousandth part of an inch, dimensions on drawings for tool work are in many cases given decimally. Trouble is experienced occasionally in reading them correctly, hence a short explanation of how to read decimals is here given. The method given, while differing from that laid down in works on arithmetic, is in common use in shops, and is especially adapted to the needs of the toolmaker on account of the graduations of his measuring instruments reading directly to thousandths of an inch. As decimals containing more than four figures are very rarely met with in tool work, their reading will not be considered here.

Rule.—*Read the first three figures to the right of the decimal point as a common fraction having one thousand for its denominator, and read the fourth figure as a fraction having ten for its denominator and one one-thousandth of an inch as a unit.*

Figures to the left of the decimal point are whole numbers and are to be read as such. Commence reading the

decimal at the first figure greater than zero, reading from left to right. For example, 1.0567″ would be read, one and fifty-six one-thousandths and seven-tenths of a thousandth of an inch; .0005″ may be read, five-tenths of a thousandth of an inch; .072″ would be, seventy-two one-thousandths of an inch. When there are less than three figures to the right of the decimal point, annex enough ciphers mentally to make three figures. Thus, .07″ would be read as though it were written .070″ and may be expressed as seventy one-thousandths of an inch, and .4″ would be read as though it were written .400″, i. e., four hundred one-thousandths of an inch.

Suppose a micrometer graduated to read to ten-thousandths of an inch is to be set to read .7653 inch. Then, since on all portable micrometers the one-thousandth of an inch graduations are independent of the vernier by which the tenth part of a one-thousandth is obtained, the micrometer would be set first to seven hundred sixty-five one-thousandths, and then, by the aid of the vernier, set ahead three-tenths of one-thousandth of an inch. By accustoming himself to read decimals in this manner, a person is less liable to make an error in setting or in reading the micrometer.

WORK OF THE TOOLMAKER.

11. In its broadest sense, the work of the toolmaker comprises the design and construction of machine tools, such as lathes, planers, shapers, etc., in addition to that of the small general tools, such as taps, dies, reamers, milling cutters, and the special tools, such as jigs, gauges, and similar implements used in the production of duplicate work. It being the tendency to specialize in every direction of machine-shop work, the journeyman toolmaker today does not generally build the machine tools himself, but, instead, produces the tools and special appliances for the construction of the machine tools in an economical manner.

The making of taps, dies, reamers, milling cutters, and

similar cutting tools forms, in most shops, but a relatively small part of the toolmaker's work, since there are many concerns making a specialty of this work. In consequence thereof, all such tools can be bought of the makers for a small fraction of what their cost would be if made singly and with the facilities usually found in tool rooms. Many of these tools thus bought are really superior to home-made tools, simply on account of the makers having the proper facilities.

As far as cutting tools are concerned, the work of the individual toolmaker is confined, except in relatively rare instances, to the making of *special* cutting tools differing in one or more dimensions or in design from the standard sizes in which the makers supply them. The production of the special tools used where articles are manufactured in quantities under the interchangeable system, and such special tools as tend to cheapen the cost of manufacture where machinery is not built in large quantities, form, in general, by far the greater part of the toolmaker's work.

MEASUREMENTS.

12. Classification of Measurements.—The measurements to be made in tool construction may be divided into two general classes: (1) *Approximate measurements;* (2) *precise measurements.* The adoption of one or the other class of measurement depends on the accuracy required. In most cases, both classes of measurement are used on a job, since a tool is rarely of such shape as to require measurements of precision for each and every part of it.

13. Approximate measurements are those made with the aid of an ordinary graduated steel scale and a caliper, dividers, scribing block, surface gauge, etc., or measurements that may be classified as direct visual measurements. While an expert using the greatest care and

working with a magnifying glass can set calipers by a steel scale within a limit of variation of .001 inch of the true size, there are rather few people that can do so. Generally speaking, the limit of variation, that is, the degree of accuracy attainable, may be placed at .002 inch; it requires quite close work to attain this accuracy.

14. Precise measurements depend primarily on gauges of various kinds that represent commercially accurate subdivisions of the standard yard. These gauges, among which may be mentioned the standard end-measure pieces made by Pratt & Whitney, and the reference disks made by Brown & Sharpe, are carefully ground and lapped to a size not varying more than $\frac{1}{100000}$ inch from the true size. Gauges of this degree of accuracy are naturally quite expensive, and hence are not intended for use in the machine shop, but rather for the testing of micrometers, vernier calipers, and similar shop-measuring instruments. The precise measurements that the toolmaker is usually called on to make depend for their precision on his sense of touch, they being chiefly measurements of contact. As a matter of course, it is here assumed that the measuring instrument used—as a micrometer, for instance—is commercially correct.

With an accurate instrument and a finely developed sense of touch, a surprising degree of accuracy can be obtained by direct-contact measurement. Instances are numerous where toolmakers have finished work that, upon testing by more refined methods, was shown to be accurate within $\frac{1}{100000}$ inch. To attain this degree of accuracy, a long training is required; however, very little work that the toolmaker is called on to do will need to be within this limit. To attain accuracy within a limit of variation of .0001 inch is possible for almost any one that possesses a sensitive touch. It may sound like a very small amount, but its magnitude will be realized very forcibly when a hardened, ground, and lapped cylindrical plug is placed between the anvils of a micrometer set to just touch the plug. Let the micrometer be

screwed up .0001 inch and let the difference in the force required to push the plug through the opening be noted. The difference will prove a surprise to any one that has never felt this demonstration of the magnitude of the tenth part of one-thousandth of an inch. While granting that an expert may attain a greater accuracy, generally speaking, the limit of accuracy of ordinary contact measurements may be placed at that figure.

15. Accumulation of Errors. — It must not be inferred, however, that all work can be done or is done within this limit of variation; while it is possible to attain this accuracy for *one* contact measurement, it is unreasonable to expect to get it when a number of successive contact measurements have to be made in order to obtain a precise over-all dimension. Naturally, the total error will very likely be more than the error of each individual measurement.

A case illustrating this is shown in Fig. 2. The problem given is one that frequently arises in one form or another.

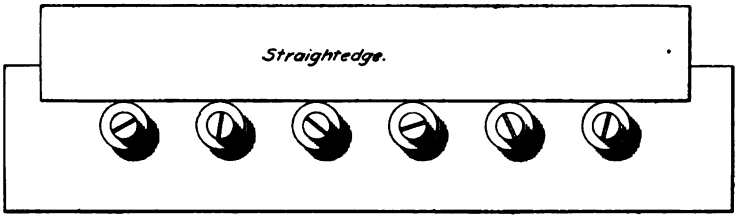


FIG. 2.

In this case, a row of six holes is to be bored in some part of a jig; the holes are to be in a straight line, equidistant, and 1 inch apart. It is required that the holes be bored with the greatest possible degree of accuracy attainable with the measuring instruments at hand, which are limited to a 1-inch micrometer. Under the circumstances, some toolmakers would locate the centers of the holes by temporarily attaching small annular circular steel disks of known diameter to the work by fillister-headed screws and placing them the required distance apart by the aid of a temporary gauge filed

up to a length equal to the center distance of two adjacent holes diminished by the sum of the radii of the two adjacent disks. If all disks are alike, the same temporary gauge will answer for each division. The disks are placed in line by being brought up against a true straightedge. The work is then placed on the face plate of the lathe and trued up until one disk runs true; the disk is now removed and the hole bored. This operation is repeated until all the holes have been bored. Now, while each hole may have been located originally within say $\frac{1}{10000}$ inch, the errors of each measurement may have accumulated until the center-to-center distance between the end holes may vary an amount considerably in excess of the limit of variation of a single contact measurement.

16. In a job of the kind here shown, the errors that prevent absolute accuracy are as follows:

1. The error of the measuring instrument. This, with an instrument purchased of a reliable maker, is usually exceedingly small.

2. Error in measuring the size of the disks. This should not exceed .0001 inch.

3. Error in making the temporary gauge. This need not be more than the previous error.

4. Error in placing the disks equidistant and at the required distance. Its magnitude will be a combination of errors 2, 3, and 4. These errors may accumulate or neutralize, partially or entirely.

5. Error in chucking the disk to run true. This error need not exceed .0001 inch if a sensitive indicator is used.

6. Error in boring. Its magnitude depends on the skill of the toolmaker; it may be infinitesimal or quite appreciable.

Examining into these errors and knowing that some of them cannot be obviated entirely, it is seen that the best that can be done is to reduce each individual error to

the lowest possible limit. The better the sense of touch is trained and the more skill is used, the closer a final result may be attained.

17. Reduction of Accumulating Errors.—We will now investigate the elimination of errors for this particular case. Suppose that a 2-inch micrometer is at the disposal of the toolmaker. Then error 3 can be eliminated entirely, since the micrometer can be used directly over any two adjacent disks. Error 4 will also be reduced, since there is one measurement less to be made for the location of any two adjacent disks; that is, there are now three contact measurements instead of four. Error 2 can be diminished when the disks are exactly alike by placing three or four of them on a surface plate, pushing them all in contact with a straightedge and one another, and then measuring their combined size, finally dividing the measurement by the number of disks. Error 1 cannot readily be eliminated by any means at the command of the toolmaker. Errors 5 and 6 can be minimized by careful work.

From the preceding discussion, it is seen that a careful study of the way in which the measurements can be made is advisable in order to secure accuracy. In general, it may be stated that, in order to secure the greatest accuracy where a number of successive contact measurements are necessary, the number of the measurements should be reduced to the smallest number feasible with the measuring instruments at disposal. When a number of successive measurements are needed for intermediate parts and the object sought is accuracy of the combined length of these intermediate parts, in addition to their own accurate location, make, first of all, the longest measurement circumstances permit, and from it obtain the subdivisions. This applies not only to precise measurements, but to approximate measurements as well. For illustration, assume that, in the job shown in Fig. 2, the distance between the end holes is required to be as precise as it can be made. Then, facilities permitting, the two disks locating them should be adjusted

first of all, and the intermediate disks from these in turn. The following may be laid down as a general rule:

Rule.—*Where several methods of measurement are feasible, the method that involves the fewest and most direct measurements should always be chosen.*

18. Considering the different methods of measurement that are feasible, it will be seen upon reflection that no rules can be given. The toolmaker must consider the means of measurement at hand and the nature of the job; he must then use his ingenuity and be guided by his practical experience.

19. For measurements that have to be made within a smaller limit of variation than is attainable by direct-contact measurements, special forms of measuring instruments based on the principle of the micrometer are used. In these machines, special devices show the *degree* of contact of the measuring surfaces with the work. They are to be found in a few of the leading shops where accurate work is done, being intended for measurements within a limit of variation of $\frac{1}{100000}$ inch. They are used rarely for work other than making standard gauges intended for testing the ordinary measuring instruments. For measurements closer than the above, a machine known as a "comparator" is used. Since it can scarcely be considered as a measuring instrument suitable for tool-room work, it will not be described here.

LIMITATIONS OF TOOLMAKING.

20. The limitations of toolmaking are twofold; they are **limitations of accuracy** and **limitations of commerce.** The first depend ultimately on the degree of skill, knowledge, and ingenuity of the individual and the mechanical resources at disposal. In many cases, a sharply defined limit is set by restriction as to cost. The second depend on the conditions of each particular case; theoretically, they

may be said to have been reached when further toolmaking fails to reduce the cost of production or to improve the quality. As a general rule, the commercial limitations are reached in practice when the cost of production has been reduced below that of competitors. At this period, in most cases, a halt is called to the devising of new tools or the improving of old ones until further advance is made necessary by competitors lowering the selling price or bettering the quality of the product.

SPECIAL TOOLS USED IN TOOLMAKING.

21. In addition to the ordinary measuring instruments and similar devices used by the machinist, the toolmaker needs an indicator for showing the truth of cylindrical work, and also a center indicator. There is quite a variety of other tools of great use to the toolmaker, but since these are fully described in the catalogues of concerns making a specialty of measuring instruments, no space will be given to them here.

The lathe indicator and center indicator have been comparatively unknown and have heretofore been made by the toolmaker himself; as a consequence there is a great variety of designs. The two instruments shown in Figs. 3 and 5 and the holder for them shown in Fig. 6 were designed by the writer and have been used by him constantly for fine work. Their construction is not covered by patents. Several firms are now making good indicators.

22. Construction of a Lathe Indicator. — The lathe indicator is shown in Fig. 3, the illustration being full size. The purpose of the indicator is to magnify any untruth of the work in order to make the error more visible; the most obvious and direct method is to use a lever with a long and a short arm. The short arm bears against the work. When the latter is revolved in the lathe, any error, due either to the work not being round or to its not being set centrally,

causes the end of the long arm to describe an arc, the length of which is directly proportional to the ratio between the lengths of the two arms. In other words, the longer the long arm is made in proportion to the length of the short arm, the more sensitive the indicator will be. In practice, it is rarely necessary or advisable to make the ratio more than 1 to 50; with this ratio, an error in the work amounting to only .0001 inch will cause a movement of the long arm

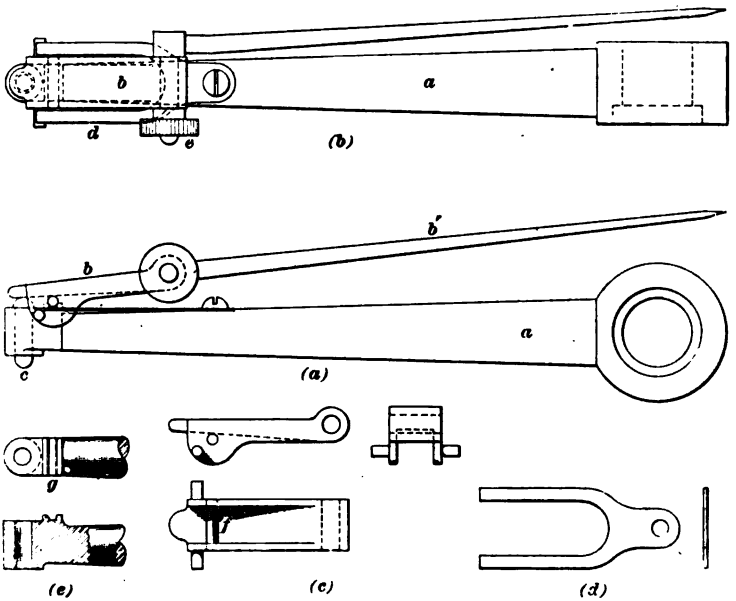


FIG. 8.

through an arc fifty times as long, or .005 inch in length. This is an amount that can plainly be seen with the naked eye. If the indicator is made more sensitive than this, it is too liable to be affected by the vibrations of the floor and machinery that exist to a greater or less degree in all shops. For special work requiring the greatest of accuracy, an indicator may be constructed with a greater degree of sensitiveness than that here recommended as the limit for general

work; in that case, it must be used in a place free from vibrations.

23. Referring to Fig. 3, views (*a*) and (*b*) are, respectively, a side elevation and a plan view of the indicator. It consists essentially of four parts. These are the body *a*, the lever *b*, the feeler *c*, and the spring *d*. For convenience, the lever is divided into two parts *b* and *b'*. They are so joined that *b'*, which forms part of the long arm of the lever, can be swiveled to any convenient position within range. By means of the locknut *e*, the two parts may be locked together after adjustment. The division of the lever into two separate parts also allows the degree of sensitiveness to be increased or decreased by the substitution of different arms. The end carrying the feeler is hardened; the hole that receives it is lapped true and smooth. The feeler itself is hardened, ground, and lapped so as to be a good sliding fit in the hole. Both of its ends are hemispherical; the upper end is enlarged to form a stop. The chief peculiarity of the lever is the manner in which it is fulcrumed, the fulcrum being so designed that not only is all wear taken up automatically, but also the possibility of any lost motion at the fulcrum is done away with. This is done without the introduction of any complicated device.

Referring to view (*c*), which is a detail drawing of the main part of the lever, it is seen that the fulcrum pin *f* is held by its ends in the two wings that straddle the end of the body *a*. This pin is hardened and lapped smooth; it is then driven home. The seat or bearing for the fulcrum pin is shown in view (*e*). A slot *g*, about two-thirds the diameter of the pin in width, is cut to a depth sufficient to have the pin clear the bottom of it. The upper edges of the slot are slightly beveled; the fulcrum pin rests on these two edges. It is held down to its seat by the straddle spring *d*, which, by reason of its bearing on the lever *between* the fulcrum and the point of contact at the feeler, holds the fulcrum pin down, prevents any lost motion, takes up any wear, and also causes the lever to follow any sliding motion

of the feeler. The straddle spring is shown in view (*d*). It should be a rather stiff spring; if made of the size shown in the drawing, it should be made from sheet steel $\frac{1}{32}$ inch thick.

24. Testing Work.—Suppose it is desired to test a piece of work to find out if it runs true on dead centers. Place the work between the centers of the lathe, and, after attaching the indicator to its holder, which is shown in Fig. 6, adjust it so that the feeler will bear hard on the work to be tested and be about perpendicular to the surface of the work. Rotate the work between the centers by hand and watch the end of the long arm. If it moves, it indicates one or both of two things: (1) The work may not be cylindrical; (2) the work may be eccentric in regard to the centers on which it has been finished.

A good idea of the kind of error may be formed by carefully watching the movement of the end of the lever. If it vibrates steadily just once for each revolution of the work, the latter is most likely to be round, but not central in regard to its centers. If the pointer moves in jumps, i. e., makes several vibrations during one revolution, the work is most likely to be out of round and it may also be eccentric. To test its roundness, caliper it in a number of directions, preferably with a micrometer. When the work is eccentric, it can often be made central in regard to its centers by carefully lapping the center or centers with a brass lap charged with emery, provided the error is very small, say .0005 inch. When the end of the long arm remains stationary, it shows the work to be both round and concentric with its centers.

25. The indicator may be applied to a hole in a piece of work held in the chuck or on the face plate, for the purpose of finding out if the axis of the hole coincides exactly with the axis of the spindle; in other words, to find out if the hole runs *true*. If the hole is too small to admit the feeler of the indicator, grind up a cylindrical plug to fit the hole nicely, and apply the indicator to the outside of the cylinder. The indicator may also be applied to the face of

work, to see if it has been faced true or runs true sidewise. Likewise, it is of great assistance in rechucking or resetting cylindrical work that is required to be chucked with great accuracy.

26. The particular design of indicator here shown, being removable from its holder, can be attached to a surface gauge and may then be used for testing the parallelism of straight surfaces. As is well known, it is very difficult to measure the parallelism of straight surfaces when they are far apart; in many cases calipers cannot be applied at all. For instance, consider the piece shown in Fig. 4. The question arises as to whether the plane of the circular ring at *a* is parallel to the plane of *b*. Evidently, this cannot be measured by calipering. But if the indicator is attached to a surface gauge, the work may be placed on a surface plate and the feeler brought in contact with the ring *a*. If its pointer remains stationary while the feeler is moved around the ring, the surfaces are parallel.

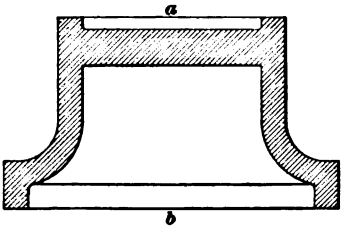


FIG. 4.

27. In order that a small motion of the end of the pointer will be visible, it is necessary to have some stationary point near it. The writer has used for this purpose a thin metal disk with a piece of soft brass wire, pointed at the end, soldered to it. The disk was placed between the joint of the holder and the joint end of the indicator; the brass wire was then bent to the shape required. If desired, some more elaborate construction may be employed.

28. Construction of a Center Indicator.—The center indicator shown full size in Fig. 5 is intended to aid in the proper location of work that is to be chucked so that a center punch mark will coincide with the axis of the live spindle of the lathe; that is, run true. The tool is essentially a lever with a long and a short arm turning about a

ball joint as a fulcrum. The indicator is clamped to the tool holder shown in Fig. 6, which is held in the tool post of the lathe; the carriage is then run forwards until the pointed end of the short arm bears lightly in the center punch mark in the work. The part *a* is made thin so as to form a spring that will hold the pointer in the center punch mark. If, on revolving the headstock spindle, it is found that the end of

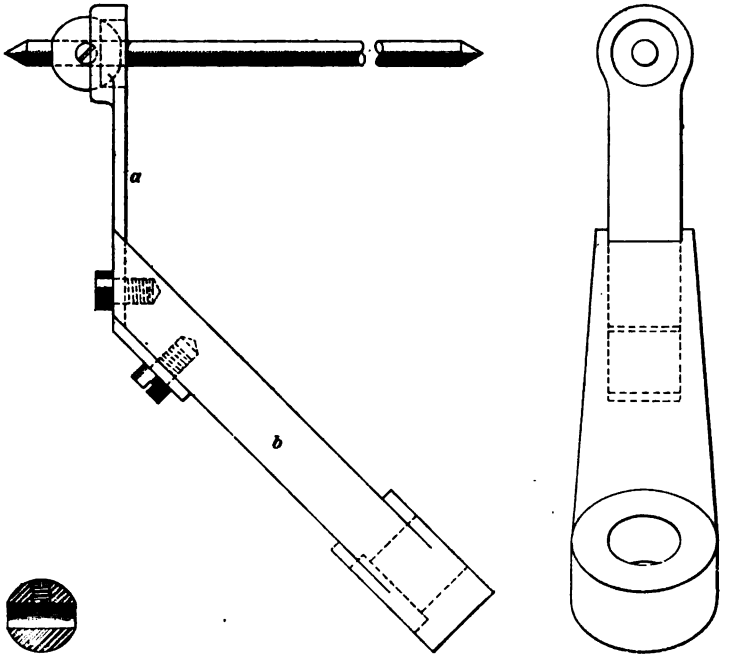


FIG. 5.

the long arm moves in a circle, it shows the center punch mark is not in the axis of the spindle, and the work needs moving until the end of the pointer remains stationary when the spindle with work attached to it is revolved. It is necessary to have some stationary point by which to observe the motion of the pointer; the dead center is the most convenient point to use.

29. If the indicator is connected to a holder in such a manner that it can be swiveled up and down, it can readily be used in all sizes of lathes. The center indicator shown possesses the advantage that there are no joints, and its accuracy is not disturbed by wearing of the joints. Furthermore, the pointer is adjustable for different degrees of sensitiveness; a small setscrew in the ball, a section of which is shown separately, is used for clamping the pointer and ball together. It is scarcely advisable to make the pointer longer than 15 inches; this length will be found to answer very well indeed. If made longer, the tool will be affected too much by the vibration of the machine.

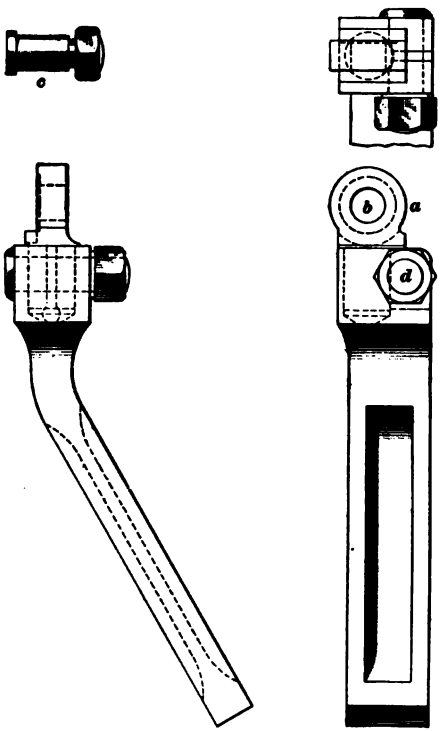


FIG. 6.

The pointer, the ball, and the head *a* should be made of tool steel and afterwards hardened. The head *a* must be drawn to a spring temper, since it serves as a spring. The ball and the end of the pointer may be drawn to a straw color. Grind together the ball and the seat in the head, using the finest flour emery. The shank *b* may be made of machinery steel and case-hardened.

30. Holder for Indicators.—The holder shown in Fig. 6 is made of tool steel. Its head *a* has a cylindrical hole *b* to receive the clamping bolt *c*, by means of which the indicators are

attached. The head has a cylindrical shank closely fitted to a hole in the holder proper. The holder is split at the front end; a clamping bolt *d* allows the head *a* to be locked in any position after rotation to the desired place. The combination of two joints allows a movement of the indicator in two planes perpendicular to each other; hence, the indicator can be swung through a very wide range of positions, and is thus adapted to almost any size of lathe and any kind of work conceivable. It is advisable to harden the holder at a rather low heat, and then draw it to a spring temper.

CUTTING TOOLS AND APPLIANCES.

DESIGN AND CONSTRUCTION OF TAPS.

FLUTES.

31. Number of Flutes.—In order to provide cutting edges, and also to provide a place for the reception of the chips, **taps** are fluted. It is almost the universal practice today to cut taps, independent of their size, up to and including 2½ inches diameter, with four flutes. For larger sizes, practice varies. Some toolmakers advocate five or more flutes for sizes above; others retain four flutes for all sizes. Generally speaking, four flutes will usually prove sufficient and satisfactory for all taps that cut a full thread of the right diameter in one operation. Special taps, or *hobs*, as they are often called, for tapping screw-cutting dies are made with from six to eight flutes; they are not intended to cut a full thread at one passage, but rather to finish out to size the hole in the die that has previously been tapped with a slightly smaller tap.

32. Forms of Flutes.—There are two different forms of fluting in common use, shown in Fig. 7 at (*a*) and (*b*), respectively. The form shown at (*a*) is considered by many

as the better form, since it makes not only the stronger tap, but also prevents the cracking of the tap lengthwise in hardening, owing to the absence of relatively sharp corners

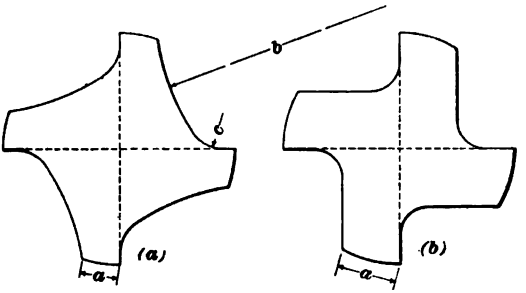


FIG. 7.

where a crack could start. The curve of the groove is composed of two arcs tangent to each other; the large arc, as *b*, may, for a four-fluted tap, have a radius equal to the diameter of the tap, and the small arc *c* may have a radius of one-sixth of the diameter. These proportions are approximate and vary somewhat, not only with different makers, but also on account of the inexpediency of having a different cutter for each different size of tap. In practice, one cutter will be made to answer for several sizes.

The fluting shown at (*b*) is probably the one in most common use, although it does not make as strong nor as easy working a tap. In order not to weaken the tap too much, the **land** *a* must be left wider than it is in Fig. 7 (*a*); this produces a greater friction in tapping. The sides of the flute are perpendicular to each other; the corner may have a radius of one-eighth of the diameter of the tap.

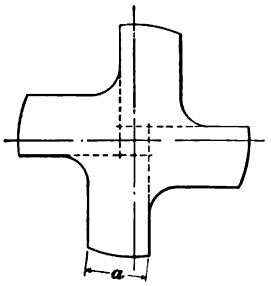


FIG. 8.

In both forms of fluting, it is the common practice to make the cutting edges radial, as shown by the dotted lines in Fig. 7. This answers very well indeed for general work. If a tap is to be used entirely for brass, and especially for brass castings, the

cutting edge may be slightly advanced in the direction of cutting parallel to a radial line, as shown in Fig. 8. This will give it a slight negative rake and cause it to cut more smoothly and with less liability of chattering. The amount that the cutting edge is advanced need not be very large; it may be from one-sixteenth to one-tenth of the diameter of the tap. Taps that are to be used for general work on all kinds of metal usually have their cutting edges radial.

HAND TAPS.

33. Design.—As the name implies, **hand taps** are intended for tapping holes by hand. Since it is rather difficult to use the tap without throwing a sideward strain on it, in consequence of which the tapped hole will be larger at the end where the tap was started, the construction should be such that it will counteract this tendency as much as possible. This is done by making the lands rather wide and giving no relief to the thread back of the cutting edge. The width of the lands for a four-fluted tap when made with flutes, as shown in Fig. 7 (*a*), may be two-tenths the diameter of the tap. When fluted with four flutes, as shown in Fig. 7 (*b*) and Fig. 8, the width *a* of the lands may be about one-fourth the diameter of the tap. The square on the end of the tap intended to receive the tap wrench is generally placed so that the corners are in line with the cutting edges.

34. Making a Hand Tap.—For a straight tap, select steel slightly larger in diameter, say $\frac{1}{16}$ inch, for sizes up to $\frac{1}{2}$ inch; $\frac{1}{8}$ inch for sizes up to $1\frac{1}{2}$ inches; and $\frac{3}{16}$ to $\frac{1}{4}$ inch larger for sizes above. Have it well annealed, preferably in slaked lime. Turn the shank and tap body to size, then mill or file the square and cut the thread in the lathe. The thread should be cut as smooth as possible; many toolmakers prefer to use the single-pointed tool for roughing out to within .002 or .003 inch of the correct size and then

finish it with a chaser. On small taps, but only when accuracy of pitch is not essential, the thread may be cut with a die. If the die is in good condition, a very good thread can be cut if plenty of oil is used in cutting; however, as with all dies that feed themselves, the pitch of the thread cut will be coarser than the pitch of the thread of the die. The thread having been cut, chamfer the end in the lathe an amount depending on whether the tap is to be a taper tap, plug tap, or bottoming tap. The tap is now ready for fluting. This can best be done in the milling machine, holding the tap between the centers or in the universal chuck, according to size. The cutter is set, by trial, to cut the correct depth of flute; large taps may require several cuts.

The flutes having been cut, the cutting edges will have to be filed up a little on the face with a rather fine file to remove the burrs left by the milling cutter, and if the tap is over $\frac{1}{4}$ inch, it had better be backed off by filing. The chamfered ends must be given clearance by filing. The size, and, preferably, the number of threads also, having been stamped on the shank, the tap is ready for hardening. To harden it, the safest way is to heat it inside of a piece of gas pipe, frequently turning the latter and changing its position. The danger of overheating and burning the steel, and of unequal heating, is greatly lessened thereby. The tap should be hardened at as low a heat as will make it hard enough so that a file will not "touch" it, dipping it vertically into clear water a little beyond the threaded part. It may then be ground in the flutes on an emery wheel to sharpen the teeth and make it bright for tempering. Draw it to a good straw color evenly all over, holding it some distance above the fire. When an emery wheel is not available, the cutting edges must be made sharp before hardening by filing with a fine file. The tap may be brightened in the flutes, after hardening, by grinding or by emery cloth, using care that the emery cloth does not touch the cutting edges; if it does, it will dull them more or less. It is best, however, not to use any emery cloth on a tap.

35. Effect of Hardening.—If the pitch of the thread and its diameter are measured after hardening, it will usually be found that the pitch and the diameter have changed a small amount. In a few instances, the tap will measure the same as before. There is no known way of preventing this change, which is due to hardening. It can be minimized by a slow, careful, and even heating, combined with a hardening at as low a heat as will be sufficient to make the tap hard. Fortunately, the amount of change rarely exceeds two-thousandths of the length and diameter, and is negligible for nearly all work.

36. Straightening Taps. — When taps are rather long, they will usually become crooked in hardening and

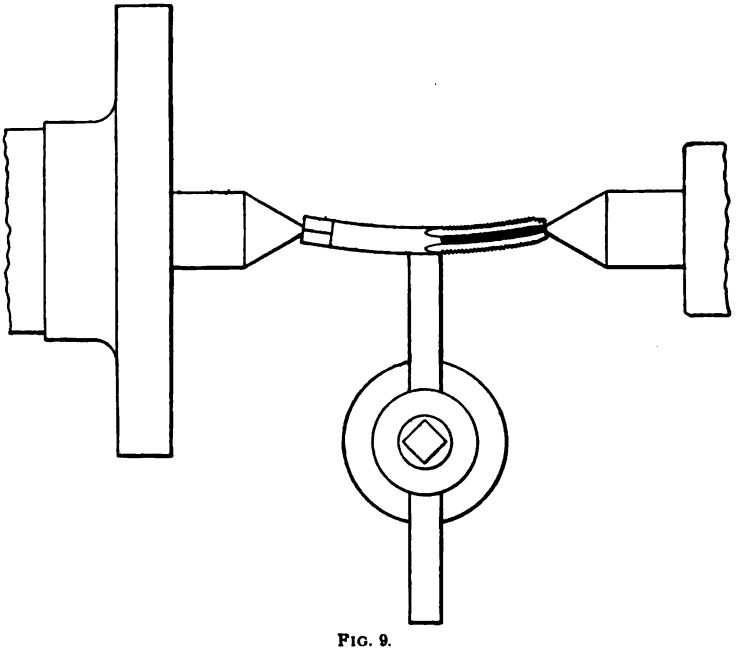


FIG. 9.

tempering. They can be straightened as follows: Place the tap between the centers of the lathe; fasten a piece of metal with a square end in the tool post and place it against the

highest point of the convex side, as shown in Fig. 9. Now, with a Bunsen burner or an alcohol lamp, heat the tap, which has been previously covered with lard oil, until the oil commences to smoke. Then, by means of the cross-feed, slowly force the tap over until it is a little crooked the other way and quickly cool it while between the centers. By repeating this operation, it may be straightened very nicely. The amount the tap must be forced over can only be ascertained by practical experience. No attempt can be made to give a rule for it. Other hardened and sprung work may be straightened in the same manner.

The tap should be straightened before drawing the temper. String solder may be used in place of oil to test the temperature when heating the tap. As quick as the solder melts, the tap is hot enough.

MACHINE TAPS.

37. Machine taps are intended for use in tapping machines, in the turret lathe, and for similar work. Since these taps are intended to be guided axially by their attachments, the lands can be made narrower than in hand taps, and relief can be given to the teeth, which causes them to cut more freely. Relief is given by filing the thread back of the cutting edge until the tap has the form shown in Fig. 10. Very little filing is necessary; it is not advisable to give too much relief, since, in backing the tap out, chips are liable to be drawn in between the work and the lands.

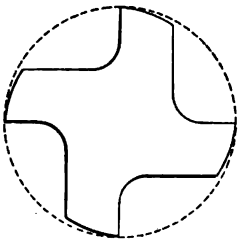


FIG. 10.

TAPER TAPS.

38. Relief.—In making a **taper tap,** attention must be paid to two points that are frequently overlooked, and in consequence of which the tap, though finely made otherwise, will produce poor work. These points are: (1) The teeth *must* be relieved back of the cutting edge; and (2) a taper

tap cannot be cut to correct pitch by setting the tailstock over and gearing up for the right number of threads per inch. A trial of a taper tap not relieved in the thread, especially if the taper is large, will immediately show that the tap, instead of cutting the metal, will squeeze it. This is due to the fact that the sides of the thread at the back of the lands drag against the work, thus preventing the cutting edges from cutting. The threads are usually backed off with a three-square file; manufacturers of taps use a special machine that relieves the thread in the process of cutting it.

39. Errors.—In order that the tap may have the correct pitch of thread, it must be cut by the use of a taper attachment. When a taper tap is cut in a lathe not fitted with a taper attachment, it is done by setting over the tailstock center. Two errors are then introduced that become more pronounced as the taper is made larger. In the first place, the pitch will be finer; in the second place, the thread, instead of being true, will be drunken. Neither one of these errors can be corrected very readily. The second error is due to the fact that, in taper turning with the tailstock set over, the work does not turn with a uniform angular velocity, while the cutting tool advances along the work with a uniform linear velocity.

When the taper is slight, the change in pitch and the drunkenness of the thread is ordinarily imperceptible to the eye; with tapers of $\frac{3}{4}$ inch per foot, the errors become sensible and increase rapidly as the taper becomes larger. For these reasons, taper taps should always be cut with the taper attachment. If none is available, there is nothing left except to set the tailstock over. The thread should then be well relieved; this will make the tap cut free, but will correct neither the pitch nor the drunkenness of the thread. In cutting the thread on a taper tap, the threading tool should be set square with the axis of the tap. This is the practice of manufacturers and is well worthy of general adoption.

40. In order that the toolmaker may determine whether the error in pitch introduced by setting over the tailstock is of sufficient importance to prohibit this method, the table below is given. In this table, the figures in the second column represent the length along the center line of the tap, in ten-thousandths of an inch, for 1 inch measured along the surface of the tap.

TABLE OF ERRORS IN TAPER TAPS.

Taper.	Length Along Axis.	Taper.	Length Along Axis.
$\frac{1}{8}$ inch per foot.	.9999	$1\frac{1}{4}$ inches per foot.	.9980
$\frac{1}{4}$ inch per foot.	.9999	$1\frac{1}{2}$ inches per foot.	.9973
$\frac{5}{16}$ inch per foot.	.9999	2 inches per foot.	.9965
$\frac{3}{8}$ inch per foot.	.9998	$2\frac{1}{2}$ inches per foot.	.9946
$\frac{7}{16}$ inch per foot.	.9998	3 inches per foot.	.9922
$\frac{1}{2}$ inch per foot.	.9997	$3\frac{1}{2}$ inches per foot.	.9895
$\frac{3}{4}$ inch per foot.	.9995	4 inches per foot.	.9863
1 inch per foot.	.9991		

NOTE.—The word *taper* is defined in a different manner by different persons; it will here be taken to mean *the difference in diameters per foot of length measured along the axis.* This definition is in accordance with the most general practice.

HOBS.

41. Design and Use.—Taps made for cutting the threads in solid and split dies for screw cutting are called **hobs.** They differ from ordinary taps chiefly in having more flutes; they are usually given from six to eight flutes. When hobs are to be used for *solid* dies, they must, of course, be of exact diameter. When used for dies *adjustable* through quite a range, it is advisable to make them larger. Their diameter may then be twice the depth of thread plus the diameter of bolt. It is recommended that the diameter of the hob should not be made larger than just given. Cutting an adjustable die with a hob larger than the screw to be cut with it, will have the effect of giving relief to the

threads of the die back of the cutting edges. In consequence of this relief, which in ordinary dies cannot readily be given in any other manner, the die will cut much more easily and cleanly. Hobs are advantageously used in connection with a leading tap slightly smaller in diameter. This relieves the hob of the most severe duty, and hence a smoother and truer hole will be tapped by it.

When making a hob, it must always be remembered that the perfection of the screw made by the die the hob is intended for, depends primarily on the hob; and hence this should be made as perfect as conditions permit. Any poor workmanship in the thread of the hob will be duplicated in the die, and usually in a more emphatic manner. A poorly cut die will naturally produce a poor screw thread. When tapping a die with a hob, plenty of oil should be used and care should be taken to see that the flutes do not become clogged with chips. Some persons do not relieve the hobs that are intended for straight dies, but taper hobs should always be relieved, for the same reason as taper taps.

The term "hob" is also applied to the milling cutter used for cutting the teeth of worm-wheels to correct shape. This style of hob will be treated of under the heading of "Milling Cutters."

42. Chaser Hobs.—Hobs for making chasers are made straight. They need not be longer than three times the width of the widest chaser that is to be cut by them. Numerous flutes are required, and, preferably, should be spaced a little unevenly. As they are intended to be used between the centers of a hand lathe, they should be provided with liberal-sized centers. A shank long enough to take a dog should be provided. For threads from 40 per inch to 8 per inch, a good size is $1\frac{1}{4}$ inches diameter, with the thread about 2 inches long, and the shank $1\frac{1}{2}$ inches long. About twenty flutes may be cut with a 60-degree cutter, making the cutting edges radial. Since the excellence of the chaser depends on the hob, the thread should be cut as perfect and smooth as possible. After hardening at a low heat, draw

the hob uniformly to a full straw color. When using it, adjust the rest to such a height that the upper side of the chaser will be about $\frac{1}{16}$ inch above the height of the center. The hob will then cut the teeth into the chaser with sufficient relief to make it cut free. The chaser itself may be drawn to a pale straw color.

ADJUSTABLE TAPS.

43. Design.—Where holes have to be tapped to a very exact size, as is often required in work done in large quantities under the interchangeable system, it is rather hard to produce solid taps that will tap the holes within the limit of variation permissible. While it is quite feasible to make them accurate within .0001 inch when soft, the change in diameter when hardening them will often go beyond the permissible limit of variation, especially when the tap is larger than $\frac{1}{2}$ inch. It is of very little use to try to make allowance for this change of diameter, since nobody can tell whether the steel will contract, expand, or remain the same diameter in hardening. For these reasons, **adjustable taps** have been designed. Some of these will cut a full thread in one passage through the work; others again can be used only for finishing a hole that has previously been tapped by a leading tap of slightly smaller diameter.

44. Examples of Adjustable Taps. — Adjustable taps may be made as shown in Fig. 11. There are four

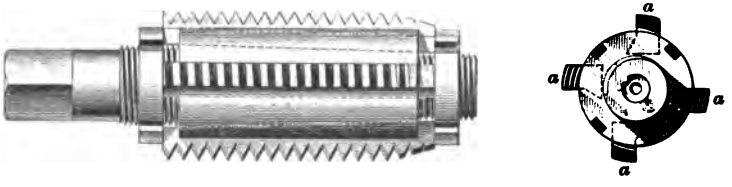


FIG. 11.

tool-steel blades *a*, *a* inserted in dovetail slots; the bottom of the slots makes an angle with the center line, or axis, of the tap. The blades are confined axially by two nuts, one

at each end. By varying the position of these nuts, the tap may be expanded or contracted a slight amount. Taps of this kind cannot ordinarily be made for sizes smaller than 1 inch, since the shank will become too small if made smaller.

45. In making such a tap, the body should be turned first. In the smaller sizes the body may be made of tool steel, and for large taps, of machinery steel. The slots can generally be cut faster and better in the shaper than in the milling machine. Cut a fine thread for the two nuts in the lathe; the diameter of the tap body, at the points where the nuts are located, is sometimes made small enough to clear the bottom of the slots. Thread and face each one of the two nuts at the same chucking, in order that the faces will be true with the thread, and make the nuts a good snug fit. The blades may now be milled or planed out of well-annealed tool steel and then carefully fitted to the slots. In order to make them of equal length, drive them into the slots and face their ends in the lathe. They should fit tightly enough not to slip during facing. Put the nuts on and screw the nut at the shank end up until it is within a short distance of the shoulder. Then tighten up the front end nut. Now turn the blades to correct size (approximately); cut the thread on the blades, using the lathe, and chamfer the front end with a square-nosed tool. Remove the nuts, mark the blades and slots with corresponding marks, drive the blades out, relieve the chamfered parts, and slightly back off the threads with a fine three-square file. The threads require backing off on account of the springing of the tap during thread cutting causing the back edge of each blade to be slightly higher than the front or cutting edge. After relieving, harden and temper the blades carefully, drawing them to a straw color. If the blades should spring very much, they must be straightened before inserting them again. Assuming the body to be of machinery steel, it may be well to case-harden the square at the end. An adjustable tap is usually set to correct size by actual trial.

46. A very simple form of adjustable tap is shown in Fig. 12. This method of construction is covered by a



FIG. 12.

patent; the J. M. Carpenter Tap and Die Company, Pawtucket, Rhode Island, are the exclusive manufacturers of these taps. As shown in the figure, the tap is split. Taper-headed screws *b*, *b* allow it to be expanded, and binding screws *a*, *a* serve to lock the two halves together.

47. Another design of adjustable tap suitable for holes that pass clear through the work, or do not need to be tapped close to the bottom, is shown in Fig. 13. The



FIG. 13.

tap is split longitudinally; the two halves can be forced apart by a centrally located screw *a* having a tapering head. After setting it, the two halves of the tap are locked together by setting up the nut *b*, which has a beveled recess that engages the conical projection at the front end of the tap. While locking the nut, the central screw must be prevented from turning by inserting a screwdriver into its slot and holding it. The nut may be made hexagonal in form at its front part, as shown, or have radial holes drilled in its circumference. In the latter case, a spanner must be made for it. In making such a tap, it is advisable to cut the thread and flute the tap before splitting it. It may be slotted slightly beyond its threaded part, the slot terminating in a hole drilled perpendicular to the axis.

MULTIPLE-THREADED TAPS.

48. Occasionally, **multiple-threaded taps** are required. If these are intended to cut a full thread in one operation, the lands back of the cutting edges must be well relieved to allow the tap to cut freely; if this is not done, the force required for tapping may be sufficient to break the tap. Generally speaking, it is better to chase the threads in the hole to be tapped and use the tap for finishing only.

SQUARE-THREADED TAPS.

49. Square-threaded taps may be fluted in the same manner as V-threaded taps. If intended to cut a full thread in one operation, the lands must be well backed off, otherwise the amount of force required for tapping will be excessive. When used merely for sizing holes in which the thread has been roughed out, very little backing off is necessary.

LEFT-HANDED TAPS.

50. If a **left-handed tap** is required, it may be designed and made in the same manner as a right-handed tap, except that the flutes are to be cut in a way the reverse of that used for a right-handed tap. All remarks previously made regarding the number of flutes and the backing off of the lands apply to left-handed taps as well. It is a good plan to stamp left-handed taps with a large L on the shank, to call attention to the fact of their being left-handed. This is to be done not on account of machinists not being able to detect the difference, but rather on account of unskilled helpers failing to distinguish between right-handed and left-handed taps

COLLAPSING TAPS.

51. Purpose of Collapsing Taps. — Taps so constructed that the blades forming the cutting edges can be moved radially at will toward or from the center, are called **collapsing taps.** They are used quite largely for work

done in the turret lathe, when the hole to be tapped exceeds 1½ inches in diameter. Their chief advantage is that they need not be turned back to withdraw them from the tapped hole; the blades are drawn in enough toward the center to clear the thread, and the tap can then be withdrawn by an axial motion. As a matter of course, nearly all the time required to wind an ordinary tap back is saved. Since a collapsing tap is quite an expensive tool, its use is limited by commercial considerations to work done in large quantities.

52. Design of a Collapsing Tap.—A simple collapsing tap designed for tapping a taper hole in brass castings is shown in Fig. 14. For this reason, the cutting edges of the blades are advanced in the direction of cutting; that is, they are given negative rake. The shank A is fitted to the turret. The end of the shank is bored out cylindrical to receive the tap body B, in which four dovetail grooves are cut, to which the blades or chasers are fitted. A circular groove d', having a square cross-section [see Fig. 14 (c)], receives the lugs d, d and confines the chasers longitudinally. The body of the tap is prevented from rotating by a pin C passing through it. This pin, while the tap is cutting, rests against the lower ends of the helical slots F and F'. When the hole has been tapped to the desired depth, the pin C is turned in the direction of the arrow. The pin then follows the helical slots and the body B

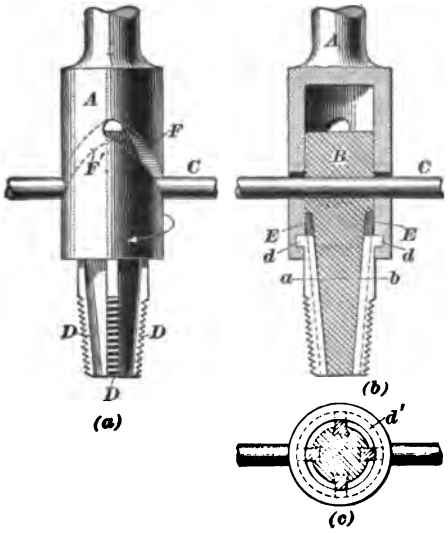


FIG. 14.

is drawn into the shank; since the dovetail grooves in which the chasers work are at an inclination to the axis, the chasers are drawn together and the tap can be withdrawn. To get it ready for work again, the pin *C* is turned back. A tap of the design shown in Fig. 14 may be used in a chuck in the lathe. When used for a turret lathe, it is almost always necessary that the hole is to be tapped to the same depth in every piece operated upon. If this is the case, it should be used in connection with an adjustable disconnecting tap holder.

53. Making the Tap Shank.—When making a collapsing tap of the kind shown, the only thing that may prove difficult will be the two helical slots. They are rather difficult to produce by hand, but if care is taken to use a helix that can be cut in the milling machine by an end mill, the slots are easily cut. If no milling machine adapted for spiral work is available, the slots may be cut in the lathe as follows: Gear the lathe to cut a thread having a pitch equal to one turn of the helix adopted. Then, with a scriber fastened in the tool post and the tap shank between the centers and forced to turn with the spindle, scribe a fine line on the shank in the proper place to represent the center line of the slot. Turn the work 180° between the centers *without* moving the headstock spindle; scribe a line again. Now throw the leadscrew out of gear and at the beginning and end of the slots scribe fine circles around the tap body. At the intersection of these circles with the helical lines, make fine center-punch marks, and divide along these lines into a sufficient number of divisions to drill out most of the stock. Center punch well, and drill out the stock, removing most of the stock between the holes with a keen-edged cape chisel. The slots may now be finished by a suitable planing tool to be held in the tool post of the lathe. The tap body is placed between the centers, and the dog properly adjusted to have the tool match the slot. A wooden wedge is then driven in between the tail of the dog and the side of the slot in the face plate that drives it; rotating the

leadscrew by hand will then cause the tool to travel along the tap body, and, if fed in by means of the cross feed-screw, it will cut out the slot. The planing tool is preferably made so as to plane both sides of the slot at once. The opposite slot may be finished in the same manner.

54. Collapsing taps may be made in a variety of designs to suit different kinds of work. Thus, where bottoming holes are to be tapped, the blades may be arranged to collapse by means of a centrally located movable stop within the tap body coming in contact with the bottom of the hole; the stop when moving back then draws the blades inward.

For some work it may be advantageous to design a collapsing tap on the lines of the ordinary scroll chuck, or the geared three-jawed or four-jawed automatic chuck. These designs will readily suggest others.

RELEASING TAP HOLDERS.

55. Purpose and Design. — In screw-machine and turret-lathe work, when holes are to be tapped to a uniform depth, it is advisable to use a tap holder that will automatically release the tap from the holder as soon as the hole has been tapped to the proper depth. Such a holder will allow

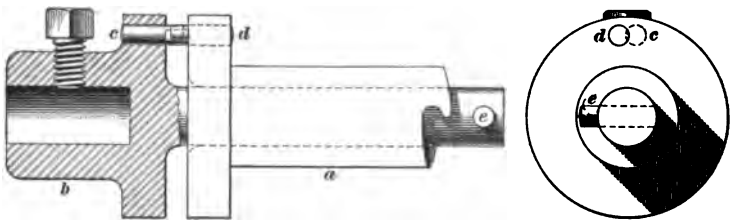


FIG. 15.

of rapid tapping, and, when properly adjusted, obviates breakage of taps through striking the bottom of the hole.

A very common and highly efficient releasing tap holder is that shown in Fig. 15, which is especially adapted to screw-machine and turret-lathe work. It consists essentially of

two pieces. The sleeve *a* has a shank that fits one of the tool holes of the turret. The tap holder proper is free to slide longitudinally within the sleeve a certain amount; when the clutch pins *c* and *d* are disengaged, it is free to rotate within the sleeve. The end of the tap-holder shank carries the backing-out pin *e*, which is so located that when the clutch pins *c* and *d* will just clear each other, it will be from $\frac{1}{8}$ to $\frac{1}{4}$ inch away from the helically formed end of *a*. The end *b* of the tap holder may be made in a variety of ways to suit the purpose. The simplest way is to make it as shown; the tap shank fits the hole and is held from turning by the set-screw. If thus made, its use is obviously limited to taps having the same shank diameter. To make it adapted to all sizes of taps, the end *b* may be a universal chuck; the holder then becomes a *universal* releasing tap holder.

56. Operation. — The operation is as follows: The shank *a* being fastened in the turret and the stop-pin *c* butting against the flange of *a* and the stop-pin *d* preventing *b* from turning, the slide of the turret is advanced and the tap then engages the revolving work. As soon as the turret slide comes against its stop, the tap, by reason of being entered in the work, is drawn forwards until *c* and *d* are disengaged, when it is free to revolve. This stops further tapping. The spindle of the machine is now reversed, which causes the work, and hence the tap, to turn in an opposite direction. The turret slide is then withdrawn to the rear; the backing pin *e* during the backward motion is guided by the helical end into the recess of the sleeve shank, and any further revolution of the tap is thus arrested. In consequence of this, the tap is backed out by the revolving work.

57. Forming the Helical End. — When making a releasing tap holder, it is well to remember that the helix at the end of the sleeve shank must be right-handed for a right-hand tap and left-handed for a left-hand tap. The pitch of the helix may be about one and one-half times the diameter of the stop-pin. The helix is most readily produced in the lathe, gearing the lathe to give the proper pitch and using a

square-nosed tool for cutting the helix. A line may first be scribed to mark the position of the helix and then most of the stock removed by drilling and chipping, leaving to the lathe tool the finishing only.

58. Proportions.—The diameter of the sleeve shank is fixed by the size of the holes in the turret for which it is intended, as is also its length. The shank of the tap holder may be about five-eighths the diameter of the sleeve shank. The three stop-pins may have a diameter equal to about one-third the diameter of the tap-holder shank. For small work, it is usually advisable to make the whole device of tool steel.

NUMBER OF TAPS IN SPECIAL CASES.

59. Taps for Square Threads.—In tapping square threads several taps are sometimes used in a set, especially where the hole is small and the pitch of the thread coarse. When the hole is long the flutes in the ordinary tap are too small to carry off the cuttings, hence more taps are used, taking smaller cuts and having larger flutes.

Sometimes as many as six taps are used in a set and if they run with plenty of oil they will clear themselves readily, cut more rapidly, and last longer without dulling. The first tap is sometimes a V-thread tap with the correct pitch, and the other taps take out the balance of the stock, gradually approaching the square shape until the correct size and form is reached.

60. Square-Thread Taps in Brass.—Where square-thread taps do not readily clear themselves of chips, it has been found advantageous to remove some of the teeth, or lands, of the tap. Sometimes every other tooth is removed, and even more than half may be removed with good effect. This is especially true when cutting square threads in brass. The reason for this is that when there is little difference

in the height of the cutting edges, they sometimes rub over the surface of the brass with a glazing effect, making the cutting more difficult. Removing part of the teeth reduces the cutting surface and permits the others to do more effective service.

TOOLMAKING.

(PART 2.)

CUTTING TOOLS AND APPLIANCES.

DIES FOR THREAD CUTTING.

CUTTING EDGES.

1. Number of Cutting Edges.—It is now the universal practice to give dies four **cutting edges** for all sizes up to and including 4 inches. Beyond that size, practice varies. Some toolmakers advocate five cutting edges for dies above 4 inches; others prefer four cutting edges for all sizes. There is no particular objection to making large dies with five or more cutting edges beyond the fact that it slightly increases the first cost.

It is generally admitted that the only instance in which it is absolutely necessary to give more than four cutting edges to a thread-cutting die is that in which part of the circumference of the work to be threaded is cut away. More cutting edges are then needed in order to steady the die and thus prevent crowding into the work on the side where the metal is cut away. The number of cutting edges may then be as given in the following table:

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TABLE OF CUTTING EDGES FOR SCREW-CUTTING DIES.

Circumference Cut Away.	Cutting Edges.
none	4
$\frac{1}{24}$	5
$\frac{1}{12}$	6
$\frac{1}{8}$	7
$\frac{1}{6}$	8

When more than one-sixth of the circumference is cut away, dies usually will fail to cut a satisfactory thread.

Attention is called to the fact that it is customary to denote the size of a die by the diameter of the screw it will cut; thus, a die that will cut a 1½-inch screw is called a 1½-inch die, irrespective of the outside diameter of the die itself.

2. Rake of Cutting Edges.—For general work and for dies that are to be used indiscriminately for iron, steel, brass and other copper alloys, it is advisable to make the cutting edges radial. For dies that are to be used entirely for brass castings, the cutting edge may recede some from a radial line, thus giving a slight negative **rake.**

NON-ADJUSTABLE DIES.

3. Making a Solid Die.—Owing to the difficulty of sharpening the cutting edges, and also owing to the difficulty of making them to an accurate size, solid dies, i. e., dies made out of one piece, are used comparatively little nowadays in machine-shop work. Being inexpensive in comparison with adjustable dies, they may sometimes be used with advantage for special work when only comparatively few threads are to be cut and no great accuracy as to size is required.

When only one die of a special size or pitch of thread is to be made, it will scarcely pay to make a hob for cutting the

thread in it. The usual way, which is also the cheapest, is to cut the thread in the lathe, provided of course the die is large enough to permit this to be done. Since it is very difficult to measure an internal thread, a male thread gauge of the required diameter and pitch of thread is first made, unless a tap is in existence that will serve as a male gauge. The thread having been cut, the beginning of the thread in the die is chamfered while still in the chuck. Cutting edges and clearance spaces are then produced by drilling and filing, and, after relieving the chamfered threads, the die is ready for hardening.

The die may be made as shown in Fig. 1. The die illustrated is round, being intended for use in the die holder of a screw machine. It may be made of any other form, however. The outside diameter of a solid die is usually fixed by the diameter of the holder that it is intended for, but should not be made less than 2.5 times the diameter of the

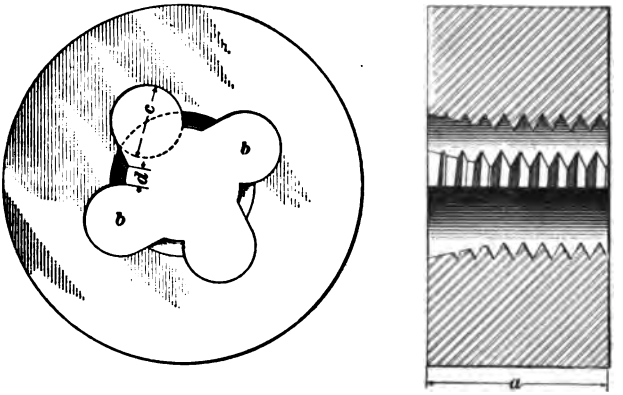


FIG. 1.

screw it is to cut. The depth a of the die may be 1.25 times the diameter of the screw, and slightly more for very small screws, such as machine screws. If four cutting edges are used, the clearance holes, as b, b, should be spaced equidistant and with their centers on a circle having a diameter equal to the diameter of the screw to be cut. The diameter c of the clearance holes is usually made one-half the size

of the die, and the top *d* of the lands about one-twentieth the circumference of the circle tangent to the lands. The cutting end of the die is to be chamfered out about three to four threads deep, as shown in the cross-section. The chamfered parts must be relieved in order to give keen cutting edges.

4. When making a solid die, cut the thread first. Then screw in a piece of steel the full length of the die and face it off flush with the faces of the die. The temporary male thread gauge previously mentioned may be used for this purpose to advantage when only one special size die is to be made. Lay out the centers of the clearance holes on the back face of the die and drill through. After drilling the first hole, insert a plug that fits tightly into the clearance hole just drilled, in order to prevent the screw within the die from turning while drilling the other clearance holes. After drilling, remove the screw and finish the back edge of the lands by filing. File the front edge carefully with a fine file to remove the burrs, relieve the chamfered parts, then harden and temper, drawing to a good straw color.

5. When a large number of solid dies of the same size are to be made, it is cheaper to cut the thread by tapping, finishing with a hob of correct size. The chamfering should be done with a suitable taper reamer prior to tapping. The clearance holes may then be drilled in a jig; with a substantial jig, if the drilling is carefully done, there will be no need of inserting a screw in the tapped hole. The holes in the jig will steady the drill sufficiently for drilling. For rapid finishing of the clearance spaces, a hardened filing jig will be found of great service. The relieving of the chamfered cutting edges is usually done by hand. While it can be done by special tools, this will rarely pay except when the number of dies is very large.

6. Inserted-Blade Dies.—When dies are required for screws larger than 2-inch, it is usually advisable to make them with blades inserted in a ring made of cast iron, wrought iron, or machinery steel. There are several

benefits gained by this construction. In the first place, it obviates all danger of losing the die by cracking while hardening; in the second place, it allows the die to be readily sharpened, since the blades are removable; and, again, after the ring or die body is once made, new blades can be made at a fraction of the cost of a solid die. The first cost of an inserted-blade solid die of small size is probably a little higher than that of a solid die up to $2\frac{1}{2}$ inches in diameter; above this size, the inserted-blade solid die is usually cheaper to construct and will give better satisfaction on account of ease of sharpening and repair.

7. A very solid and simple inserted-blade solid die is shown in Fig. 2. Dovetailed slots, with the sides radial, are

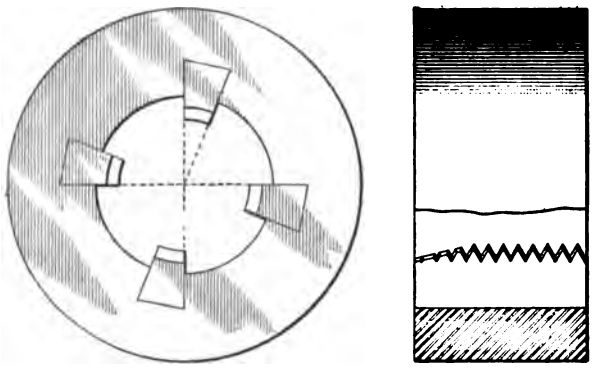


FIG. 2.

planed in a ring of suitable inexpensive material and dovetailed blades are well fitted to the slots, being made a driving fit therein. The blades are then faced flush with the sides of the holder; the thread is now cut in the lathe, the beginning of the thread chamfered off for three to four threads, as shown in the partial cross-section, and the blades, after being properly marked, are driven out. They are then relieved on the chamfered part, hardened, tempered, and driven home again in their proper places as marked.

For dies larger than 2-inch, the following proportions will serve as a guide, where d = diameter of screw; outside

diameter of die body = 2.4 to 2.5 d; inside diameter of die body = 1.3 d; length of blade = 1.25 d; width of lands, when four blades are used, as is recommended for general work, about one-sixteenth the circumference of the screw to be cut. When more blades are used, the lands must be made narrower. If the nature of the work demands it, the blades of an inserted-blade die may project somewhat beyond the faces of the die body. They should not project more than the width of the lands, however; otherwise they are liable to break off under the strain of cutting.

ADJUSTABLE DIES.

8. There is a great variety of **adjustable dies** made for general work. Since special sizes of these, for use in the ordinary die stocks, can be obtained of the makers for less than they can generally be made in the tool room, the toolmaker is rarely called on to make them. If such should be the case, there are generally dies at hand that will serve as a guide in making a special die.

9. Spring Die. — In many cases spring dies for screw-machine work are, for various reasons, made in the tool room, although, generally speaking, they may be bought more cheaply from concerns making a specialty of taps and dies.

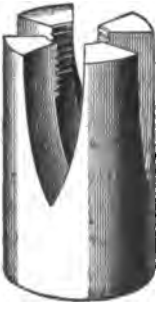


FIG. 3.

These dies are always used with a clamp collar that serves to adjust them. When a spring die is to be made, it is good practice to fit it to one of the clamp collars at hand, thus saving the expense of making a new clamp collar. Provide four cutting edges for general work, making the lands about one-sixteenth the circumference. Chamfer about three to three and one-half threads and relieve to give keen cutting edges. The depth of the thread may be about one and one-quarter times the diameter of the screw to be cut. For the cutting edges, use a 45° milling cutter that will split the die as shown in Fig. 3. Tap the die with a hob the same size as

the screw to be cut. After splitting the die, the burrs thrown up on the threads may be removed by running the hob through again. Finish the cutting edges by filing with a fine file, stamp the size and the number of threads on the die, and then harden as far as the end of the thread and temper to a deep straw color.

For accurate uniform threads, two dies must be used, one for roughing out and the other for the finishing cut. To do good work, the cutting edges must be kept sharp; dies made as shown in Fig. 3 can readily be sharpened by grinding the face of the lands on a suitable emery wheel.

10. Average proportions of spring dies are given in the following table, where all dimensions are given in inches. It is to be understood that the proportions given are intended only as a guide, and, hence, may be departed from to some extent to suit special requirements.

TABLE OF SPRING-DIE PROPORTIONS.

Size of Screw.	Outside Diameter.	Length.
$\frac{1}{8}$ to $\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{4}$
$\frac{1}{4}$ to $\frac{3}{8}$	$\frac{3}{4}$	$1\frac{3}{4}$
$\frac{3}{8}$ to $\frac{1}{2}$	1	2
$\frac{1}{2}$ to $\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{2}$
$\frac{3}{4}$ to 1	$1\frac{3}{4}$	$2\frac{3}{4}$
1 to $1\frac{1}{4}$	2	3
$1\frac{1}{4}$ to $1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$
$1\frac{1}{2}$ to $1\frac{3}{4}$	$3\frac{1}{4}$	4
$1\frac{3}{4}$ to 2	$3\frac{1}{2}$	$4\frac{1}{4}$

When spring dies are to be used for work whose circumference is partly cut away, make the number of cutting edges as given in the table of Art. **1.** A cutter to suit the increased number of cutting edges will then have to be selected for slitting the die. The spring die is probably the cheapest adjustable die for screw-machine and turret-lathe work up to and including 2 inches in diameter, as far as

first cost is concerned. When threads larger in diameter are to be cut, it is usually more economical to use some form of adjustable die with inserted blades.

11. Inserted-Blade Adjustable Die. — One of the simplest designs of an adjustable die with inserted blades is that shown in Fig. 4. The blades are inserted exactly as in

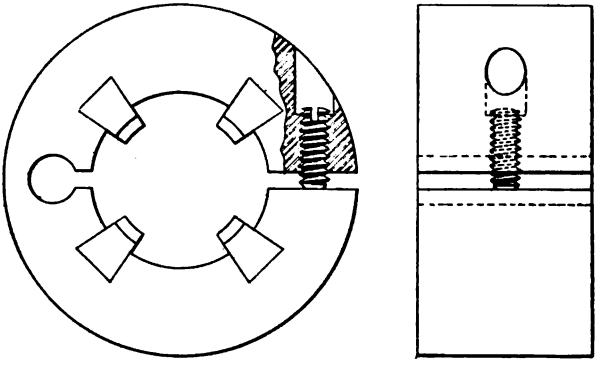


FIG. 4.

the die shown in Fig. 2; the die body is then split, as shown, and an adjusting screw put in. When this die is used in its holder, the setscrews of the holder will lock the die firmly together. Its only drawback is the necessity of removing the die from the holder every time it is desired to adjust it. This may be overcome, however, by cutting a hole through the holder in the proper place to allow the adjusting screw to be reached with a screwdriver. For very large dies, two adjusting screws may be provided, locating each near one of the faces.

The only thing that may prove difficult to one that has never done this before is the drilling and counterboring of the hole for the adjusting screw. This job may be done in a jig if a large number of dies are to be made; in case of a limited number, it may be done in a lathe or a milling machine, strapping the die body to the top of the slide rest or to the milling-machine platen. Using a two-lipped milling cutter of correct size, the counterbore can, by careful

feeding, be cut without much trouble. Drilling is then done while the die body is still strapped down, catching the drill in a chuck. If the die body has been split prior to drilling the hole for the adjusting screw, an iron or wooden shim should be inserted in the slot.

DIE HOLDERS.

12. For screw-machine and turret-lathe work, solid and adjustable dies are inserted in releasing die holders made on the same principle as a releasing tap holder. The die is held in the holder by three or four pointed setscrews that enter conical depressions, as shown in Fig. 5. These

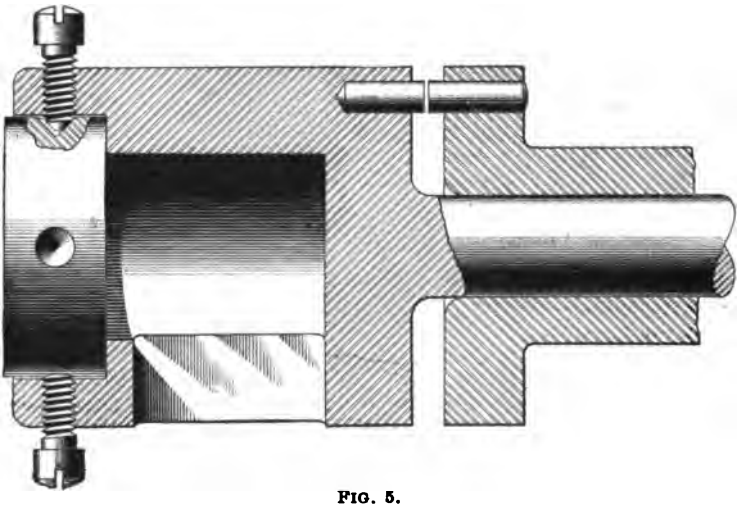


FIG. 5.

depressions are so located that the tightening up of the setscrews will draw the die against the shoulder of the holder. The length of the die holder naturally depends on the length of the screw to be cut. One or two liberal-sized openings should be cut through the holder back of the die, to provide for free escape of the chips. Practical considerations prohibit the use of the holder shown for very long screws. For these a releasing holder may be constructed in a somewhat

different manner, retaining the same principle of releasing and clutching for backing the die off.

13. A design for such a holder is shown in Fig. 6. It consists essentially of two parts, a shank *a* to fit the turret and a die holder *b*. The clutching and releasing mechanism

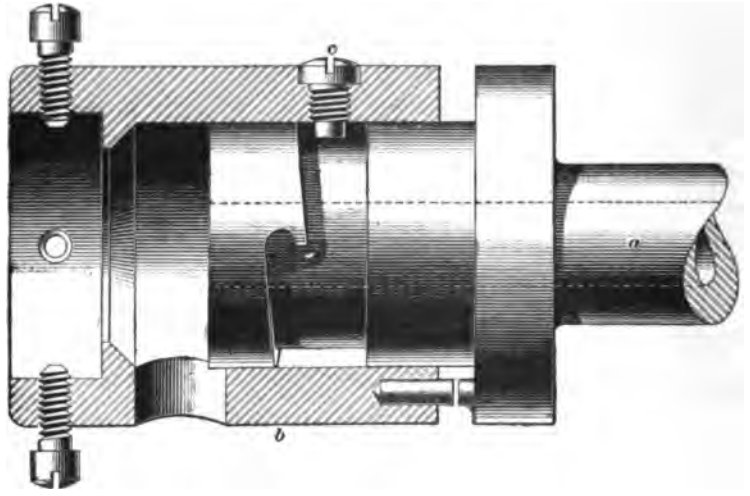


FIG. 6.

is contained in the front part of the device. For releasing, two stop-pins are employed; the one is driven into the holder and the other into the shank, as shown. The forward part of the shank is enlarged and grooved to receive the end of the backing pin *c*, which in the design here illustrated is firmly screwed into the holder proper. The forward side of the cylindrical groove forms a helix that serves to guide the backing pin into its place. The die holder proper is bored to be a good sliding fit on the front end of the shank. In the position shown, the clutch pins are disengaged and the holder is free to rotate about the shank. If the turret is now withdrawn while the work just threaded is revolving in a reverse direction, the backing pin *c* is guided into place, clutches the shank, and the die is unscrewed from the work. The shank has a hole drilled through it to admit the threaded work.

In designing such a holder, care should be taken to locate the backing pin and the groove so that the groove will not be uncovered when the backing pin clutches the shank. If the die holder is to be used for a right-hand die, the helical side of the groove must be right-handed, that is, as shown in the illustration. For a left-handed die, it must be left-handed. If desired, the device may be adapted to both right-handed and left-handed threads. To do this, the enlarged end of the shank is made long enough to receive two grooves; the front side of one is then made a right-handed helix, and the front side of the other a left-handed helix. A hole to receive the backing pin is drilled and tapped for each groove; the backing pin may then be changed from one groove to the other. A blank screw should be provided to fill the backing-pin hole not in use. Also provide one or two openings for the escape of chips. The helical side of the groove is most conveniently cut in an engine lathe geared to the correct pitch, which may be about one and one-half times the diameter of the backing pin.

REAMERS.

CLASSIFICATION OF REAMERS.

14. Reamers may, in accordance with their shape, be divided into three general classes. These are **straight reamers, taper reamers,** and **formed reamers.** Each of these classes may be divided into three subclasses, in accordance with their construction. These are *solid reamers*, *inserted-blade reamers*, and *adjustable reamers.*

Reamers are generally intended for the production of round smooth holes of accurate size. In some cases, they are merely intended to enlarge holes without particular reference to the holes being true and straight. Experience has shown that, in order to produce round and smooth holes, reamers must have their cutting edges spaced and formed

correctly. It must not be inferred from this statement, however, that there is but one correct way of spacing and forming the cutting edges; the required result may be arrived at in various ways.

CHATTERING.

15. Chattering, which is a common fault of reamers, is in itself an evidence of incorrect design or construction of the reamer. It is due to several entirely preventable causes, any one of which, when present alone or in combination with one or more of the others, will induce it. Whether a chattering reamer can be cured or not depends on its design and construction.

A knowledge of the causes that induce chattering of a reamer will indicate whether it can be cured or not. The causes of chattering are as follows:

1. Equidistant spacing of the cutting edges.
2. Excessive front rake of the cutting edges.
3. Excessive clearance of the lands.

If the cutting edges are spaced equidistant around the circumference, each edge will follow in the track of the others. Experience has shown that this condition is not conducive to the production of a round hole. Excessive front rake will cause the reamer to cut too freely, or "take a greedy bite," as it is called. This precludes the possibility of producing a smooth hole, since smoothness can be attained more readily by a scraping cut. Excessive clearance, or relief, of the lands robs the reamer of the support it should derive from them; consequently, it works unsteadily and with a wobbling motion.

SPACING OF CUTTING EDGES.

16. Two different systems of **spacing** are in general use, either one of which will tend to prevent chattering. One system is shown in Fig. 7. In this, the cutting edges

are spaced irregularly and no two edges are diametrically opposite each other. In order to show clearly the irregularity of the spacing, a supplementary dotted circle has been drawn and divided into equidistant divisions. Since no two edges are opposite each other, the diameter of the reamer cannot be measured by calipering and it can only be brought to size by fitting it to a ring gauge of correct size.

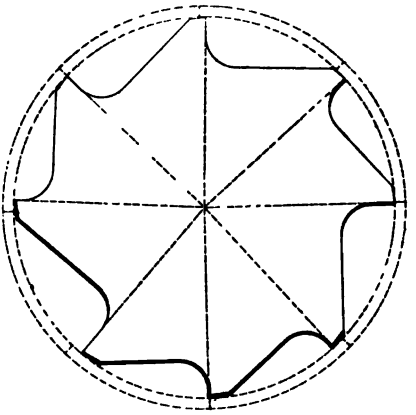


FIG. 7.

This drawback is overcome in the system of spacing shown in Fig. 8. Here the spacing is so arranged that any two opposite cutting edges are on the same diameter. Hence, the reamer can be calipered, and, for this reason, the general adoption of this system of spacing is recommended. While Figs. 7 and 8 show a section of a solid reamer, the methods of spacing shown apply to inserted-blade and adjustable reamers as well.

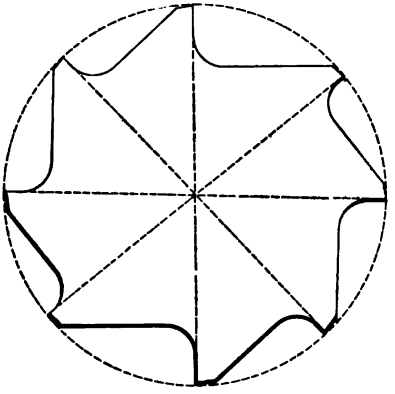


FIG. 8.

NUMBER OF CUTTING EDGES.

17. Fluted reamers for lathe and hand work, with the exception of rose reamers and special reamers designed to rapidly remove a relatively large amount of metal, are rarely given less than six cutting edges. For solid reamers, the number of cutting edges may be as given in the following table:

TABLE OF CUTTING EDGES FOR REAMERS.

Diameter of Reamer.	Cutting Edges.
$\frac{1}{8}$ to $\frac{1}{2}$	6
$\frac{1}{2}$ to 1	8
1 to $1\frac{1}{2}$	10
$1\frac{1}{2}$ to $2\frac{1}{4}$	12
$2\frac{1}{4}$ to 3	14

Generally speaking, there is nothing to be gained by giving a larger number of cutting edges than that given in the table.

18. In inserted-blade reamers, the largest number of cutting edges that can be given depends on the thickness of the blades. They are usually made with less cutting edges than solid reamers. It was believed formerly, and the view is still held by many, that a reamer must have an odd number of cutting edges in order to work well. Actual experience with properly formed reamers has demonstrated conclusively that, as far as truth, ease of working, and smoothness are concerned, it does not make the slightest difference whether the number of cutting edges is odd or even. On account of being able to caliper the reamer, an even number of cutting edges is really preferable. Rose reamers may be given from three to seven flutes, according to size. In the small sizes, they may be made without any teeth between the flutes, and, in the large sizes, may have one or two teeth between each flute.

FLUTING.

19. A form of flute that is very satisfactory is that shown in Figs. 7 and 8. This form of flute leaves the reamer very strong and, at the same time, by the absence of a sharp corner, reduces the possibility of the reamer cracking in the corner of the flutes in hardening. Another

good form of flute is that recommended by Brown & Sharpe, which is shown in Fig. 9. This form gives a greater clearance space than the flute with sides at right angles to each other. Milling-machine cutters for this form of flute may be obtained from the Brown & Sharpe Manufacturing Company. These cutters are to be set so as to give a slight negative rake to the cutting edge. To allow the negative rake to be seen plainly, two dotted diameters have been drawn in Fig. 9. When using this form of flute, the cutter must be set to such a depth that the land will be about one-fifth the average distance from one cutting edge to the next. If the flute is cut deeper, the cutting edges become too springy for good work. When flutes of the form shown in Figs. 7 and 8 are used, the lands may be about one-eighth the average distance from one cutting edge to the next.

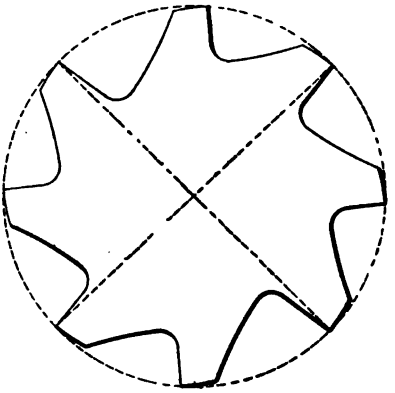


FIG. 9.

In general, a reamer will work more smoothly if the cutting edge is given a slight negative rake, since it will then take a scraping cut. The amount of negative rake need not exceed that shown in Fig. 9, which is about 5°. If the reamer is to be used entirely for steel, the cutting edges may be radial, like in Figs. 7 and 8.

CLEARANCE.

20. In order that the reamer may cut freely, the lands must be relieved back of the cutting edge. This relief can be given either by grinding the reamer with an emery wheel in a suitable fixture, or by oilstoning. The amount of clearance to be given depends on the purpose of the reamer. If it is to be used for roughing out, the clearance should be

more than is given to a finishing reamer. It should be least for a finishing reamer that is intended to keep its size for a long time. Fig. 10 shows the appearance of reamer teeth properly relieved for different purposes.

In Fig. 10 (*a*), the relief to be given to a roughing reamer is shown. If the lands are thus relieved, the reamer will

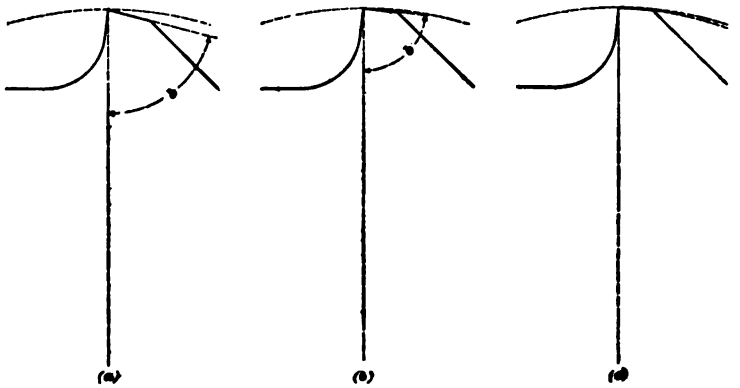


FIG. 10.

cut freely, but cannot be expected to make as true a hole or last as long as the reamer having its teeth relieved as shown in Fig. 10 (*b*). This latter form of relief leaves the cutting edge better supported, and, consequently, the reamer will work more smoothly and keep its size longer than with the form first shown. It will not cut as freely, however. Fig. 10 (*c*) shows the form of clearance to be adopted when it is important to reduce the wear of the reamer to a minimum in order to produce a large number of holes of the same size. As shown, the land is backed off on the arc of a circle. The amount of clearance at the back edge is made the same as in Fig. 10 (*b*), but, owing to the circular form of the relief, the cutting edge is supported better. If desired, roughing reamers may be backed off on the arc of a circle; however, this is more expensive than the flat backing off shown.

The amount that the back edge of the land should clear cannot be definitely expressed by any simple rule, since it

depends on several variable factors. As an aid in deciding what clearance to give, it may be stated that, for a roughing reamer, the angle *b*, see Fig. 10, may be about 80°. For a finishing reamer, the angle *b* may be from 85° to 88°, using the smaller angle for brass, which, in general, requires more clearance.

HELICAL CUTTING EDGES.

21. In order to prevent a reamer from drawing into the work, the cutting edges may be cut **helically**, choosing a left-handed helix for a straight reamer that is to turn right-handed. The helix should be such that the cutting edges will make an angle of about 15° with a plane passing through the axis of the reamer. Right-handed helical cutting edges are of advantage for taper reamers having a very coarse taper, and for formed reamers that differ considerably in their various diameters, as it will assist them to cut. Finishing taper reamers and finishing formed reamers may have their cutting edges left-handed, if made helical. Some toolmakers claim that if thus formed, owing to the shaving cut taken, they will produce a smoother and truer hole than can be obtained otherwise.

The advantages of helical cutting edges for straight reamers are somewhat doubtful, at least for general work; many toolmakers believe that the extra expense involved in making them is not justified by the results, claiming that, with reasonable care, just as true and smooth a straight hole can be obtained with a reamer having its cutting edges straight. Helical cutting edges for straight reamers are recommended when holes are to be reamed that are pierced crosswise by openings. All remarks previously made in regard to spacing, number, and clearance of cutting edges apply to helical cutting edges as well.

ALLOWANCE FOR GRINDING.

22. Since there is no way of preventing a reamer from warping in hardening, an allowance must be made to allow it to be finished by grinding. The amount to be allowed

for grinding depends on the length and diameter of the reamer; it is least for a short and most for a long reamer. For reamers up to $\frac{3}{4}$ inch, and not over 6 inches long, exclusive of shank, an allowance of .025 inch will usually prove ample, since there is no particular difficulty in straightening the reamer sufficiently to allow it to be trued with this allowance. For every $\frac{1}{4}$ inch the reamer is above this size, the allowance may be increased .01 inch, provided the reamer is not over 8 diameters long. If longer, the allowance for grinding should be increased.

GRINDING REAMERS.

23. For **grinding reamers,** a grinding machine is most convenient, although straight and taper reamers can be ground true by other means if the shop has no grinding

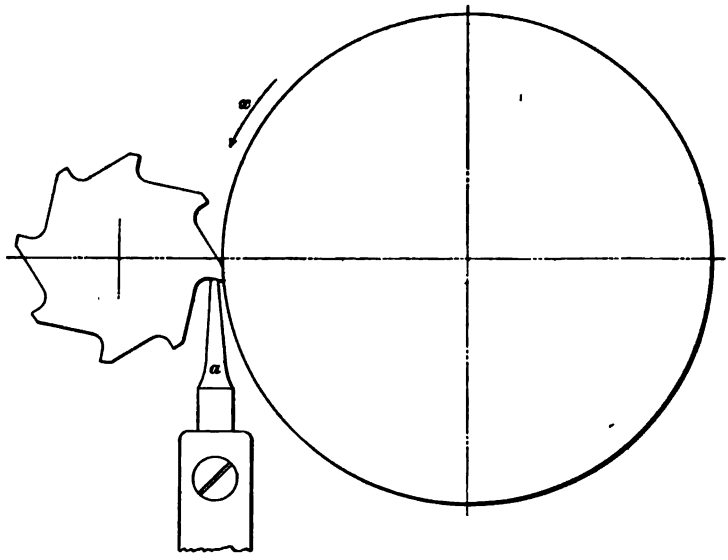


FIG. 11.

machine or grinding fixture for converting a lathe temporarily into a grinding machine. The reamer should first be ground to run true, revolving it between the centers. It

may be ground, according to its size, to within $\frac{1}{1000}$ or $\frac{2}{1000}$ inch of the finished size. The clearance is then ground with the emery wheel so set that its periphery will clear the front edge of the tooth succeeding the one being ground. The reamer is kept from rotating by a finger so adjusted that the correct clearance will be ground. The relative position of emery wheel, reamer, and guiding finger is shown in Fig. 11. The guiding finger *a* is fastened right in front of the wheel to the carriage that carries the emery wheel and travels along with it, thus always supporting the reamer tooth directly at the point where the wheel is cutting. The emery wheel should always rotate in such a direction that in grinding it tends to press the reamer tooth down on the finger, thus preventing rotation of the reamer during grinding.

The arrow *x* shows the correct direction of rotation of the emery wheel. As shown in the figure, the height of the finger is so adjusted that the cutting edge is *below* the line joining the centers of the reamer and emery wheel. The farther the cutting edge is placed below the center line, the greater the clearance produced by the wheel; conversely, the nearer to the center line, the less the clearance. From this, it is seen that varying amounts of clearance can be obtained with the same wheel and on the same reamer by varying the height of the finger.

24. In grinding the clearance, the metal must be removed by a succession of light cuts, going successively around the reamer. It is of the utmost importance that the temper of the cutting edge should be preserved; a heavy cut taken with a dry emery wheel is almost certain to anneal the cutting edge, thus rendering the reamer worthless. The clearance must not be ground up to the cutting edge; according to the size of the reamer, it may be ground to within from .01 to .02 inch of the edge. The reamer is then brought to a sharp edge and to correct size by oilstoning. For grinding the clearance, as large an emery wheel as the machine will handle should be used, since the larger the

wheel, the less concave the clearance will be. A small wheel will grind the clearance so hollow that the cutting edge will be deprived of support.

25. If no grinding machine or fixture is available, a straight or taper reamer may be ground in a lathe to run true. A piece of free-cutting oilstone, preferably of Washita stone, is held in the tool post. The reamer is revolved *backwards* at a high speed and the oilstone brought up by means of the cross feed-screw until it slightly engages the reamer. The carriage is then rapidly moved back and forth by hand; if freely lubricated, the oilstone will gradually cut the reamer down until it is round and true. Clearance is given entirely by oilstoning at a right angle to the axis of the reamer. The method here given is naturally very slow and expensive and is to be recommended only as a makeshift. It is doubtful whether a reamer can be made as round and true by it as can be done by a grinding machine, or by means of a proper grinding fixture.

GROOVING REAMERS.

26. A reamer can be **grooved** most rapidly in a milling machine with a suitable cutter. As a makeshift, the grooves can be planed in the lathe, shaper, or planer. This is not recommended, however, except when no milling machine is available.

Suppose the method of spacing in which any two opposite teeth are on the same diameter has been selected. Then, the grooves are most advantageously cut in pairs; that is, after milling one groove, the one diametrically opposite is cut before passing to the adjoining one. This is recommended on account of the saving in labor accomplished by it. In the method of spacing selected, any two opposite grooves will have the same depth, and any two adjoining grooves will differ in depth. Consequently, by adopting the method of cutting the grooves in pairs, the number of times the cutter must be reset is reduced to one-half of what it would be when cutting one groove after another.

27. The irregularity of spacing is obtained by moving the index pin a different number of holes for each adjoining pair of grooves. The irregularity introduced need not be very large; one that will cause the cutting edge to diverge by 2° to 4° from the angle corresponding to an equal division will be sufficient.

An example will show how the irregularity is introduced. Suppose we wish to cut a reamer with 8 cutting edges, and that the milling machine available requires 40 turns of the index pin for one revolution of the index-head spindle. Then, with the index pin adjusted to the circle having 20 holes, $20 \times 40 = 800$ holes must be passed over for a complete revolution of the reamer, and $800 \div 8 = 100$ holes for dividing into eight equal divisions. As a movement of 800 holes causes the work to revolve through 360°, the angle through which it is revolved by a movement of 1 hole is $\frac{360}{800} =$ say $\frac{1}{2}°$, or .5°.

If we wish to introduce an irregularity of 2°, it needs a movement of $\frac{2}{.5} = 4$ holes. Then, by a judicious selection, we arrange the number of holes to be passed over for each division. For instance, we may use successively 95, 99, 105, and 101 holes for adjoining grooves, and, after cutting each groove, give 20 turns to pass to the opposite one. With this number, the greatest difference between adjoining gooves is that corresponding to $101 - 95 = 6$ holes, which is about $6 \times \frac{1}{2} = 3°$. If the number of holes selected for successive grooves had been 98, 102, 106, and 94, the greatest difference between adjoining holes would have been that corresponding to $106 - 94 = 12$ holes; or $12 \times \frac{1}{2} = 6°$. In selecting the holes, it must be remembered that the sum of the holes must be equal to one-half the number of holes required for a whole revolution of the reamer. Consequently, the number of holes required for the last groove is equal to the difference between the sum of the preceding ones and the number of holes required for one-half of a revolution of the work.

The moves that are to be made successively in order to

obtain the spacing are as follows for the particular division and spacing selected: Referring to Fig. 12, to cut the first groove, none; to cut the fifth groove, 20 complete turns of the index pin; to cut the fourth groove, 95 holes, or 4 turns and 15 holes; to cut the eighth groove, 20 complete turns; to cut the seventh groove, 99 holes, or 4 turns and 19 holes; to cut the third groove, 20 complete turns; to cut the second groove, 103 holes, or 5 turns and 3 holes; and to cut the sixth groove, 20 complete turns. A movement of 101 holes, or 5 turns and 1 hole, will bring the cutter to the fifth groove again, and 20 complete turns to the first groove.

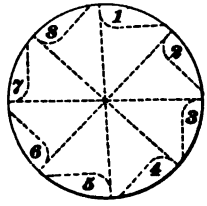


FIG. 12.

When making a solid reamer, it is necessary to go around twice, sinking the cutter in deep enough the first time to distinctly mark the position of the cutting edge. When back to the first groove, the cutter may be sunk deep enough to give the proper width of land, which can be determined readily if the position of the cutting edge of the adjoining groove is known. Then, after cutting grooves *1* and *5*, the cutter must be reset to the proper depth for grooves *4* and *8*, *7* and *3*, and, finally, *2* and *6*. If the grooves are helical, the spacing is obtained in just the same manner.

28. It must not be inferred that it is necessary to use the 20-hole circle for an 8-grooved reamer, or that the number of holes passed over for each division must be just as given in the preceding discussion. The numbers of holes and the 20-hole circle have been arbitrarily selected in order to illustrate the principle involved.

TEMPER OF REAMERS.

29. The cutting edges of a reamer may be tempered to suit the service to be performed. When the reamer is to remove a relatively large amount of metal in one operation, the cutting edges should be soft and tough enough to stand

the strain of cutting; when a reamer is intended for finishing and accurate sizing of holes, where it has to remove only a very small amount of metal, it can advantageously be made quite hard. A roughing reamer, after being hardened so that a file will not touch it, may be drawn to a full straw color, while a finishing reamer may be left a pale straw color. If the finishing reamer is intended for very light service, and if it is essential that the wear of the reamer be reduced to its lowest limit in order to make a large number of holes uniform in size, it may even be left as hard as fire and water can make it, provided, of course, that the steel is not heated hot enough to burn it.

TAPER REAMERS.

30. If intended for finishing, **taper reamers** are made on the same principles that govern the construction of straight reamers. Roughing taper reamers are often made in the same manner, but with right-handed helical cutting edges. If the taper of the reamer is at all large, the roughing reamer may be made as shown in Fig. 13. This con-

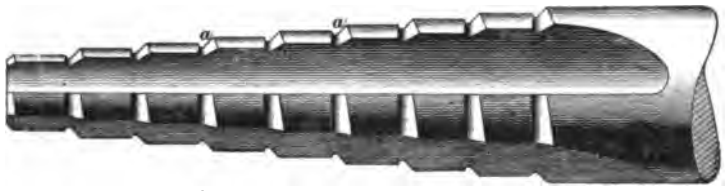


FIG. 18.

struction is an extension of the principle on which a counterbore is based; in fact, each step in conjunction with the adjoining one forms a counterbore. All cutting is done at the forward end of the steps; the cutting edges, as *a*, *a*, are formed by backing off with a file. The parts of the cylindrical surface of each step, which remain after the grooves are cut, are left cylindrical; no clearance is given, as they serve the purpose of guiding the succeeding cutting edges.

The reamer may be given four cutting edges, which may be cut with a milling cutter suitable for a tap of the same size.

If the reamer is to be used for brass or cast iron, the flutes may be made straight, as shown in the figure; if it is to be used for roughing wrought iron and steel, the flutes may be helical, using a right-handed helix of such a pitch that it will make an angle of about 15° with a plane passing through the axis. The reamer being intended to turn right-handed, the cutting of right-handed helical flutes has the effect of giving keen cutting edges, which will make the reamer work easily; at the same time, the chips are crowded back toward the shank. When turning up a stepped reamer, it is advisable to neck it down a little with a round-nosed tool at the end of each step. When grinding, the grooves allow the grinding wheel to pass entirely over the surfaces, and, furthermore, they make it easier to sharpen the cutting edges. The cutting edges are backed off by filing before hardening; when grinding the steps, the extremity of the cutting edges of each step can be trued at the same time, removing as little metal as possible. They are finally brought to a sharp edge again by careful hand grinding on a beveled emery wheel, or by oilstoning.

Stepped reamers may also be made of suitable form to rough out holes that are to be finished with formed reamers. The number of steps that are to be used for a stepped reamer must be decided separately for each particular case, bearing in mind that the greater the number of steps for a given length of reamer, the less work will be left for the finishing reamer.

31. If a number of taper reamers of the same size and taper are required, and especially if they are constantly in use and must frequently be reground or replaced, a gauge to which they can be fitted becomes an absolute necessity. The gauge may be a hole of proper size and taper in a cylindrical piece of tool steel that has been hardened and ground. With careful use, such a gauge will last practically a lifetime.

ENLARGING WORN SOLID REAMERS.

32. In spite of the most careful use, reamers will wear, and hence will ream holes smaller than the standard size for which they were made. The question of when a reamer has worn enough to become unserviceable must be decided on its own merits in each particular case; it is utterly impossible to lay down any rule for it. When a finishing reamer has worn down too much, it may either be converted into a roughing reamer, or be restored to its former size by annealing it and then upsetting it sufficiently with a round-nosed calking tool to allow it to be reground to its former size after hardening. To upset it, the reamer may be held between lead jaws in a vise; the calking tool is then applied to the face of the cutting edges, a little below the edge. When driven into the face with a hammer, it forces the edge outwards, thus making the reamer larger in diameter. This operation of enlarging a worn reamer can rarely be done more than once.

SHELL REAMERS.

33. **Shell reamers** may be given the same number of teeth, and have their cutting edges formed in the same manner, as any solid reamer. In making a shell reamer, it is well to make the hole slightly smaller and then grind it to correct size after hardening and tempering. The hardening process is likely to change the diameter of the hole, and is sure to throw it out of round; hence, in order that the reamer may fit its arbor well, the hole must be ground. The cutting edges may then be ground while the reamer is mounted on its arbor. If the reamer is worn below size, it may often be restored by the means described in Art. **32**; however, since it is not possible to tell whether the hole will enlarge or become smaller, there is no certainty about whether it can be used on the same arbor afterwards. If the hole is made tapering, it can usually be done; if the hole is straight, this is rather uncertain.

ROSE REAMERS.

34. As **rose reamers** cut on the end only, the grooves with which they are to be provided along their cylindrical surface need not be of the same shape as those of other reamers. A semicircular milling cutter having a width equal to about one-quarter the diameter of the rose reamer will cut an excellent groove, the depth of which may be about two-thirds the width of the cutter. After hardening and tempering, grind and leave the cylindrical part truly circular. True up the extreme cutting edges at the same time and bring to a sharp cutting edge again by careful grinding on a beveled grinding wheel, or by oilstoning.

35. Rose reamers for small work can be made advantageously of drill rod, which can be obtained very closely agreeing with the diameter corresponding to its nominal size. Commercial drill rod in sizes up to No. 1, Brown & Sharpe drill gauge, will rarely vary more than $\frac{1}{1000}$ inch from its true size and be surprisingly straight. Such small rose reamers are often made without flutes, and answer quite well where extreme accuracy is not required. Furthermore, they are quite cheaply made in a speed lathe and, since they are hardened only at the very cutting end, need no grinding for ordinary work. When making small reamers from drill rod, it is advisable to neck them down back of the cutting edge, as shown in Fig. 14; the diameter at the neck may be from $\frac{3}{1000}$ to $\frac{4}{1000}$ inch smaller than the rod. It has been



FIG. 14.

observed when hardening drill rod at the end, that it will often swell, that is, become slightly larger in diameter, directly back of the hardening. By necking down the rose reamer where the swelling is likely to occur, any danger of having the reamer bind in the hole is obviated.

Rose reamers made of drill rod up to and including No. 1 gauge size may be given three cutting edges. After beveling the end of the reamer in the lathe, the flutes may be filed in with a three-square file, preferably filing them as shown in the illustration, which has purposely been enlarged in order to show the cutting edges clearly. If thus made, the reamer, while cutting, will tend to push the chips ahead; this feature contributes to the smoothness of the hole reamed by it, since there is little danger then of the flutes becoming clogged. After giving clearance to the cutting edges, harden at the very end and temper. A very smooth hole can be obtained if the outer corner of each cutting edge is slightly rounded over with an oilstone.

CHUCKING REAMERS FOR ROUGHING.

36. While rose reamers are commonly used in screw machines, chucking machines, and lathes for roughing out cored holes, they are really better adapted to finish reaming. Other forms of reamers are better adapted to roughing out, as they will cut much faster and be more economical in maintenance. One of the best reamers for roughing out cored holes in chucking work is a reamer that may be called a **multiple-lipped twist drill,** made with three or four cutting edges. They are usually made as shell reamers in the larger sizes, and as solid reamers in the smaller sizes. The flutes are cut on a right-handed helix of such pitch as to give the cutting edges an angle of about 15° with a plane passing through the axis. An end view of a four-lipped twist drill is shown in Fig. 15.

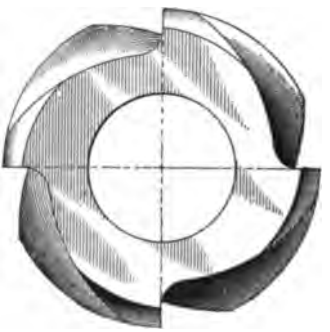


FIG. 15.

Milling cutters suitable for making this form of groove can be obtained of the Brown & Sharpe Manufacturing Company, Providence, Rhode Island, on regular order for

sizes up to 3 inches. These drills are sharpened, like twist drills, by grinding on the ends. They are made like rose reamers with no relief given to the lands between the grooves, the lands serving to guide the reamer straight. The helical grooves give keen cutting edges and insure that the reamer clears itself of chips. If made as a shell reamer, the hole must be ground to size after hardening and tempering. The outside may then be ground to size, with a taper of about .001 inch to the inch, being smallest at the back end, to prevent roughing up or binding in the hole, while the reamer is mounted on its own arbor. As reamers of this kind are intended for roughing out, it is unnecessary to grind them to correct size within a fractional part of a thousandth of an inch. This applies to other roughing reamers as well. For a four-lipped twist drill, the width of the lands may be about one-tenth the diameter of the drill. The hole, if the reamer is made as a shell reamer, should in general not be larger than one-half the outside diameter. The grooves may be spaced slightly irregular, preferably so that opposite cutting edges are on the same diameter. For small work, three grooves will work fairly satisfactorily.

ADJUSTABLE REAMERS.

37. Reamers are made **adjustable** within narrow limits for two different purposes. In the first place, reamers are made adjustable for the purpose of readily taking up the wear and allowing several sharpenings without losing the standard size. Such reamers are purposely so made that the size to which they are set cannot be varied without machine work, the idea being to keep the user from tampering with the size. On the other hand, reamers may be made adjustable for the purpose of allowing the diameter of the hole reamed by them to be slightly varied either way from the standard size. They are then made to be adjusted by the user, while the former is adjusted by the toolmaker. To distinguish between the two designs, many toolmakers confine the term **adjustable reamer** to reamers that cannot be

adjusted without machine work, and call a reamer intended for varying the diameter of the hole an **expanding reamer.**

38. There is an infinite number of designs possible for making a reamer adjustable. Some of these are shown; these designs are not offered as finality, but as suggestions. In general, the smaller sizes of adjustable and expanding reamers can be bought of the manufacturers more cheaply than they can be made, and it is only in the larger sizes or in special reamers that there is any economy in making them in the tool room.

39. The design of reamer shown in Fig. 16 is an adjustable reamer. It consists of a body containing a number of dovetailed grooves cut at an inclination to the axis. Blades that form the cutting edges are carefully fitted to these slots. These blades butt against the shoulder of the collar *a* at the back end and are firmly held against it by the locknut *b*. In order to show the blades clearly, the locknut has

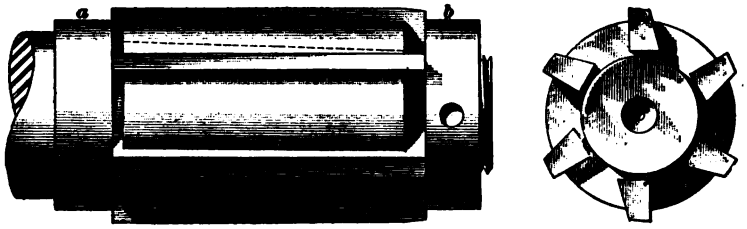


FIG. 16.

been omitted in the end view. When the reamer has worn sufficiently below size to make it unserviceable, the nut *b* is loosened, the blades are partially driven out, and the shoulder of the collar *a* is faced off sufficiently to make the reamer slightly over size when the blades are driven home again. The blades are then reground and stoned to standard size.

The design shown can readily be converted into an expanding reamer by placing a nut in the place occupied by the collar *a*. By varying the position of the two locknuts, the blades can then be expanded or contracted slightly. In

designing such a reamer, it is well to bear in mind that the range of expansion for a given longitudinal movement can be increased by making the inclination of the slots with the axis greater. The slots are usually planed in on the planer or shaper. This, in general, is cheaper than milling them.

40. The design shown in Fig. 16 is suitable for holes that pass clear through the work. If the hole is blind, however, it cannot be reamed to the bottom, since the locknut projects beyond the end of the blades. The design shown in Fig. 17 may then be adopted. In this, the slots are

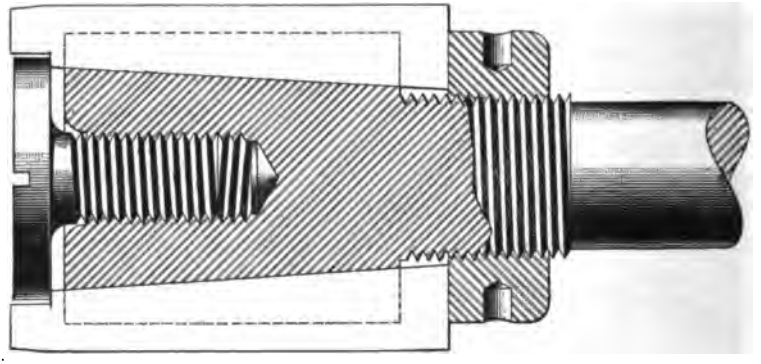
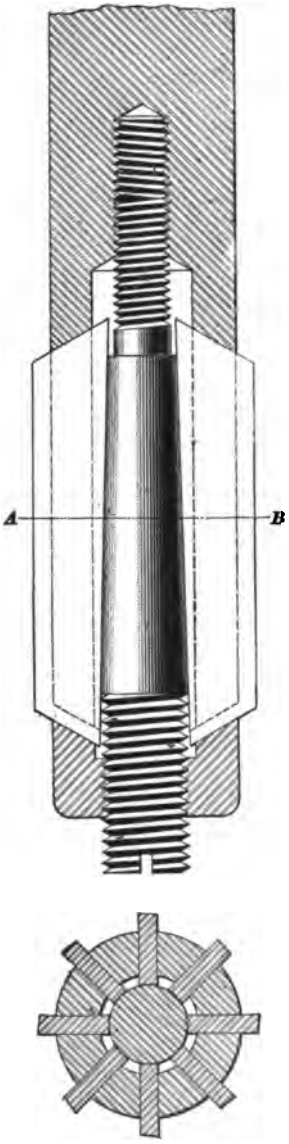


FIG. 17.

inclined the opposite way from that shown in Fig. 16. Instead of a locknut, a flat-headed screw is used at the front end, which bears against a shoulder on the under side of the blades. By means of this screw and the locknut at the back, the blades may be forced outwards or drawn inwards. The design illustrated is for an expanding reamer; it may readily be used for an adjustable reamer by making the locknut at the back end screw against a shoulder. In that case, to adjust it, the shoulder is turned down; the back nut is then screwed tight against it and the front screw hove up in order to lock the blades.

41. An inserted-blade expanding reamer of somewhat different construction is shown in Fig. 18. In this design, the blades are flat and consequently easily fitted. The

blades are beveled at the front and back; the slots that receive the blades are also beveled at the back end. A central tapered pin bears against the bottom of the blades; by screwing the pin in or out and screwing up the locknut, the blades are forced outwards or drawn inwards. The blades, after hardening and tempering, require to be ground flat and parallel on the sides; they must be a good fit in the slots. The inner face of the blades, which bears against the taper pin, should also be ground straight on a surface grinder. The taper pin may be hardened and drawn to a purple color; it should then be ground true. After assembling the reamer, adjust the pin and locknut so as to be midway between its two extreme positions and then grind the outside to standard size. Relieve and taper off the ends as in any other reamer. The locknut may preferably be hardened, but the body of the reamer should be left soft. The body should be made of tool steel in the smaller sizes, i. e., for sizes below 1½ inches. Above this size, it may be made of machinery steel. The design shown in Fig. 18 is suitable for reamers from ¾ inch up.



Section on line A B.
FIG. 18.

42. The most common forms of expanding reamers are shown in Fig. 19. In both designs, the reamer is made at first exactly as if it were a solid reamer; an axial hole is

then drilled and tapped for the adjusting screw, and, finally, the reamer is split. Referring to Fig. 19 (*a*), the reamer is split at the end. Screwing the taper-headed screw inwards

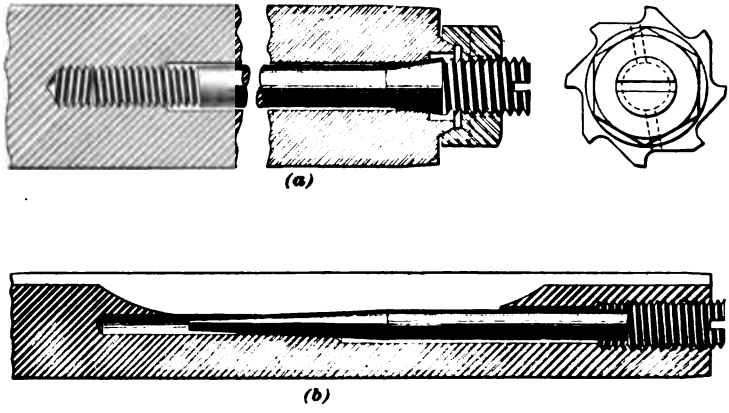


FIG. 19.

expands the reamer; it is then locked by the locknut shown. This reamer becomes large at the end.

In the design shown in Fig. 19 (*b*), the end is left solid, but the reamer is split by sinking in a narrow milling cutter right back of the end. The slots may commence at a distance from the end equal to about one and one-half times the diameter of the reamer. The length of the slots should be about four times the diameter of the reamer. The number of parts into which the reamer is split varies with the diameter. Reamers up to $\frac{3}{8}$ inch may be split into two parts; up to $\frac{3}{4}$ inch, into three parts; and above that size, into four parts.

Split expanding reamers are the cheapest expanding reamers to construct; they are open to the objection, however, that expanding does not change their diameter uniformly throughout their length. Whether this objection is serious enough to prohibit their employment for a particular case must be decided upon the merits of the case.

The diameter of split expanding reamers depends on the service expected of them. If they are made expanding simply

in order to be able to ream holes to a standard size, they should originally be ground and stoned to the standard diameter. If they are intended to ream holes at will slightly above or below standard size, they must be made slightly under the standard size.

FORMED REAMERS.

43. When holes that are neither straight nor conical (tapering) are to be finished by reaming, so-called **formed reamers** must be used. Some shapes of formed reamers can be readily ground in the ordinary grinding machine; others, again, require special apparatus for their production. Formed reamers in general are avoided as much as possible, as they are very expensive in first cost and exceedingly difficult to duplicate if a great degree of accuracy is required. There are some jobs, however, that simply cannot be done without them; in that case, the toolmaker must use his ingenuity as to the best way of grinding them to correct size and shape.

FOUR-SQUARE REAMERS.

44. If a long hole is to be finished very true and very smooth, as, for instance, the bore of a rifle barrel, a type of reamer differing entirely from any shown heretofore must be used. This type, which is shown in Fig. 20, is very little known outside of armories, where it is used practically to the exclusion of all other reamers for the purpose of finish-reaming the bore of gun barrels. It is well adapted to similar machine-shop work.

The reamer is made of square tool steel. The four sides are hollowed out, as shown in the end view. If the reamer is large, this may be done in the milling machine, shaper, or planer; for small reamers, it may be done by filing. The reamer is then hardened and tempered and ground on the surface grinder, grinding the corners only, until it is perfectly straight and parallel. Its diameter across corners is

made $\frac{3}{1000}$ to $\frac{4}{1000}$ inch smaller than the diameter of the hole to be reamed. It is then stoned carefully to give very smooth edges, using the finest grade of Arkansas oil-stone. The extreme ends are slightly tapered off by stoning. In use, a slip of hard wood, as *b*, which extends the whole length of the reamer, is inserted between one side of the reamer and the walls of the hole. This causes the edges *a*, *a* to cut. After passing through the hole, a strip of tissue paper is placed between the reamer and the slip of wood; this causes the reamer to take another cut. This is repeated until the hole is the correct size. Copious lubrication is essential to good work. The slip of hard wood may be confined longitudinally by two pins, as shown. A reamer of this kind is suited only for removing minute amounts of metal. But, on the other hand, it will produce a degree of finish that cannot be excelled by any other kind of reamer. It requires pulling through the hole in order to work best. A four-square reamer may be made without hollowing out the sides; it is then, however, more difficult to sharpen when worn. The length of a four-square reamer may be about eight times its diameter.



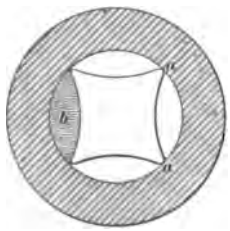


FIG. 20.

FRONT CHAMFER.

45. Straight reamers intended to cut at their ends only, like rose reamers and chucking reamers, are to be made with a very slight taper for clearance.

This taper is so slight that the part back of the cutting edges still serves as a guide. Straight reamers that have their cutting edges formed on their circumference require the front end to be slightly **chamfered** off in order that they may enter the hole easily.

COUNTERBORES.

46. The design of a **counterbore** depends on several conditions, which are: the nature of the metal it is to be used for, the range in the size of holes to be counterbored, the number of holes to be counterbored, and the distribution of metal around the hole.

SOLID COUNTERBORE.

47. When a counterbore is to be used for a relatively small number of holes and is to be thrown away after serving its purpose, it is advisable to adopt a cheap construction in order to reduce first cost to the lowest limit. Probably the cheapest counterbore that can be made is the **two-lipped flat counterbore** with a solid teat, which is shown in Fig. 21. This can be forged very near to shape, and needs

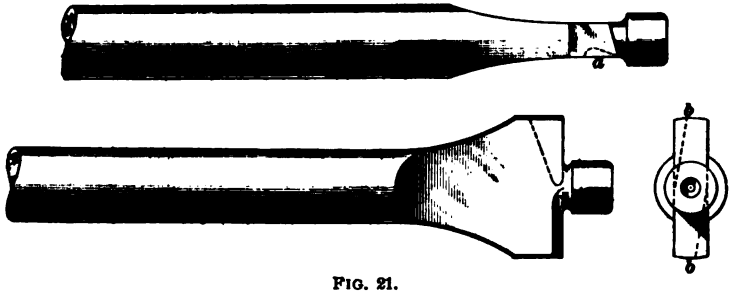


FIG. 21.

but little machine work and filing to make it serviceable. After forging, center at both ends; turn the shank to the required size; then reverse and turn up the teat, finishing it with a fine file. Turn the counterbore to correct size and

face the cutting edges. Finish by filing the sides smooth and give clearance to the cutting edges. If the counterbore is to be used for wrought iron or steel, a keen cutting edge may be given by filing as shown at *a* in dotted lines. For cast iron and brass, it is better to leave the cutting edges without any front rake. A slight relief may be given to the faces *b*, *b* to prevent them from binding in case the countersinking is to be carried to an appreciable depth. If the counterbore is intended only for squaring up the face around a hole, no relief need be given to *b*, *b*. Only the cutting edges need be hardened; they may be drawn to a straw color. The process of hardening leaves the teat hard; some toolmakers draw the end of the teat to a blue color by inserting it into red-hot lead for the purpose of preventing its breaking off. Since the teat is most liable to break off close to the cutting edges, however, and since it cannot be drawn to a spring temper clear up to the edges without partially softening them, many toolmakers believe that it is a waste of time to draw the teat to a higher color than the cutting edges.

48. When a hole is drilled close to a projection, and when it is required that the counterbore should cut part of the projection away, it is better to use a counterbore with four cutting edges. This may be turned down from bar tool steel and have its cutting edges formed by cutting grooves with a 60° cutter in the milling machine. The grooves may be cut on a right-handed helix, making an angle of about 15° with a plane passing through the axis of the counterbore if it is intended for wrought iron and steel. For brass and cast iron, the grooves may be straight. The cutting edges are to be given clearance by filing; it is advisable to give clearance to the lands also. The counterbore will then have much less tendency to spring from the projection while cutting part of it away.

49. Solid counterbores, while cheap in first cost, are open to two serious objections. In the first place, they are difficult to sharpen; in the second place, they are limited in

their range to holes as large as the teat or larger. They can be adapted to holes larger than the teat by forcing a bushing over it. As it is rather difficult to remove the bushing, this method of making a counterbore adapted to several sizes of holes can only be considered as a makeshift, especially as the difficulty of properly sharpening it is retained. Two-lipped and four-lipped solid counterbores are sharpened by grinding—on the sides, in case of a two-lipped counterbore, and on the flat side of the grooves in case of a four-lipped counterbore.

BUILT-UP COUNTERBORES.

50. Inserted-Teat Counterbore.—The counterbore shown in section in Fig. 22 overcomes the objections raised against the solid counterbore. It is slightly more expensive to make, but will serve for a greater variation in size of hole than any other. In addition, it can be sharpened very easily. As shown in the figure, it has a central hole bored to receive the shank of the teat, which is held in place by the setscrew. After turning the outside, the central hole



FIG. 22.

may be bored true and reamed, running the large end of the counterbore in the steady rest. The grooves may then be cut between centers in the milling machine, or the counterbore may be held in a chuck, as is most convenient. A 60° milling cutter should be used if four cutting edges are given. For wrought iron and steel, the grooves may be cut along a right-handed helix; for brass and cast iron, they may be straight. After hardening and tempering, the hole should be lapped out; teats of the desired sizes may then be turned and fitted to the counterbore. These teats

may be hardened at the end and drawn to a straw color. Unless the counterbore is used for exceptionally fine work, there is little need of grinding the teats to run true. As they are to be hardened at the extreme end only, there is little likelihood of their springing sufficiently to interfere with the working. The shank of the teat should be a good sliding fit, so that it may be easily removed when the set-screw is loosened. The counterbore can readily be sharpened by grinding on the end after the teat is removed.

51. Inserted-Cutter Counterbores.—When but very few holes of a special size are to be counterbored, and there is little likelihood of the counterbore ever being wanted again, the simple form shown in Fig. 23 may be adopted. Its chief recommendation is its cheapness. The objectionable feature is that it can take but a relatively light cut, which requires careful feeding to prevent breakage of the cutter. It consists of a bar that fits the hole to be counterbored, and a cutter driven into a circular hole drilled clear through the bar. For small counterbores, the cutter may be made of drill rod. Referring to Fig. 23, after the bar is turned to a fit, the hole for the cutter is drilled and reamed



FIG. 23.

and a blank piece of drill rod of sufficient length driven in. This is then turned to the correct diameter and faced on the front side. It is next driven out of the bar and filed to a cutting edge, as shown, giving front rake for wrought iron or steel. The cutter is now hardened all over and driven home again.

52. For large work, a counterbore may be made as shown in Fig. 24. The bar is slotted and a flat cutter is closely fitted to it; the cutter is confined by a key, as shown. A moderate range of variation in the diameter of

the counterbored hole is obtained by setting the cutter out of center. The cutter is readily sharpened. Whether to harden the end of the bar or not must be decided upon the merits of the case. Many toolmakers believe that it is

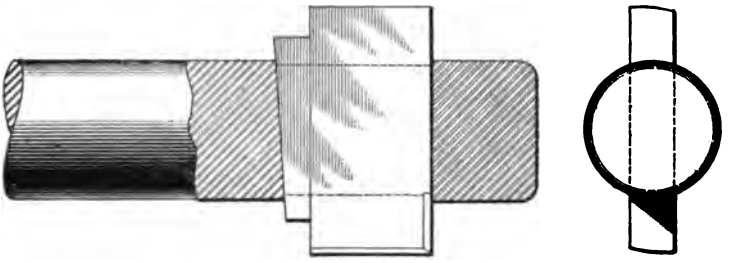


FIG. 24.

the best plan to leave the end of the bar soft and to turn it down sufficiently to receive a hardened bushing that is a good snug fit and kept from turning by a pin.

HOLLOW MILLS.

SOLID HOLLOW MILLS.

53. Hollow mills are chiefly used for screw-machine and turret-lathe work for roughing down and finishing stock

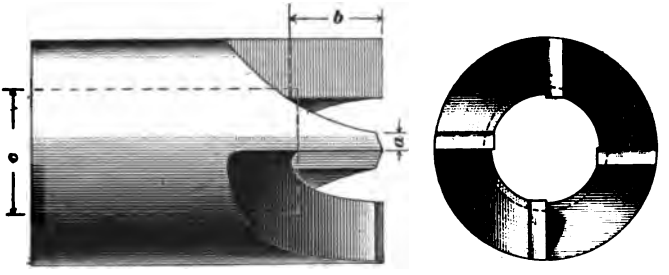


FIG. 25.

preparatory to threading. When intended for finishing, they are usually made adjustable. For roughing out, solid mills are preferred, since, in general, they are not as

springy as adjustable mills. Hollow mills may be made in a great variety of forms. For small work, the most common form is the solid mill shown in Fig. 25. This is commonly made with four cutting edges formed by milling with a side milling cutter of about double the outside diameter of the mill. In order that the mill may work easily, it must be relieved inside by filing it as shown. The rear of the mill is to be bored larger in diameter than the cutting end. This allows it to clear on long cuts, and, at the same time, makes it easier to file the clearance. In making the mill, it is advisable to mill out the cutting edges before giving the clearance inside; if this is done, the clearance can be filed more rapidly, since there is then but a relatively small quantity of metal to be removed. The milling cutter is to be set by trial until it makes *a* about one-sixth the inside diameter and *b* about eight-tenths of the inside diameter. The back of the mill may be bored about one and one-fifth times the diameter at the front end. The faces on which the cutting edges are located are usually spaced equidistant and lie in planes passing through the axis. The mill is hardened as far back as the end of the milling and drawn to a straw color from the back, setting it on a red-hot piece of iron. All sharpening is done by grinding on the end.

54. An adjustable hollow mill may be constructed in the same manner as the adjustable spring die shown in Fig. 3, using a clamp collar to adjust it.

INSERTED-BLADE HOLLOW MILLS.

55. For large work, hollow mills may be made with inserted blades, constructing them if desired non-adjustable in the same manner as the solid die shown in Fig. 2. If desired adjustable, a design similar to that shown in Fig. 4 may be adopted.

56. A very good design of a hollow mill with removable blades and adjustable for sizes within narrow limits, is shown

in Figs. 26 and 27. Fig. 26 shows the mill taken apart; Fig. 27 shows it assembled.

The mill consists essentially of a body *a* in which a number of slots, as *b*, are cut at an inclination to the axis. These slots receive the cutters *c*, *c*, which are a loose fit in them.

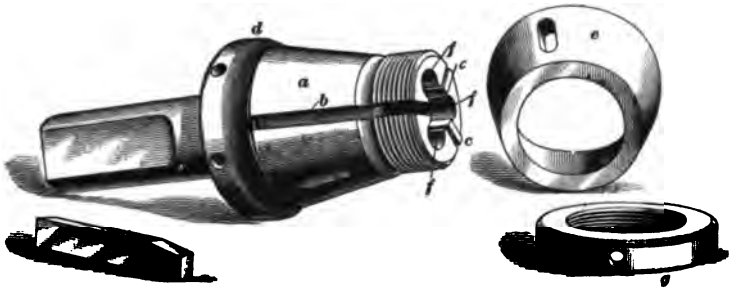


FIG. 26.

The cutters are rectangular in cross-section; their rear end butts against the adjusting nut *d*. They are held in place by a tapering collar *e*, which surrounds them and is pushed home by a locknut *g* located at the front end. The inside of the collar *e* is bored out sufficiently large to clear the body *a* and to fit the outside of the cutters, which extend slightly above the tapered surface of *a*. Clearance spaces



FIG. 27.

for the reception of the chips are cut between the slots, as shown at *f*, *f*. These clearance spaces communicate with the outside by an opening cut through the body and a corresponding opening in the collar. To set the mill to a smaller size, the locknut *g* is loosened in order to loosen the cutters.

These are then pushed forwards, and, consequently, closed in by turning the adjusting nut *d* forwards. Tightening the locknut forces the taper collar over the cutters and thus locks them. In order to set the mill to a larger diameter, the cutters are loosened by unscrewing the locknut; the nut *d* is then turned back and the cutters pushed against it by hand. They are locked again by screwing the locknut home.

A hollow mill constructed in accordance with this design is rather expensive as far as first cost is concerned. It is very economical in its maintenance, however, since new cutters can be made for it at a very slight cost. By making the cutters of suitable shape, the mill can be adapted to a limited range of sizes.

57. When making the mill, it is advisable to cut the bottom of the slots at the same distance from the axis, in

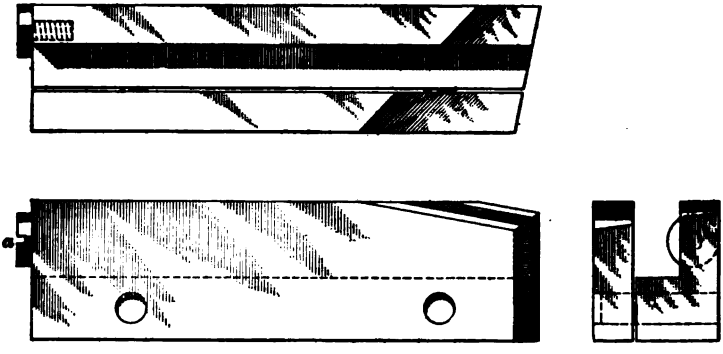


FIG. 28.

order that the cutters may all be alike. After the first set of cutters has been made, a filing jig may be constructed, in which spare cutters can be filed exactly alike in height, length, and shape of cutting edge. A simple filing jig for this purpose is shown in Fig. 28. It consists of two parts doweled together. One of the cutters out of the first set made serves as a model; it is placed between the two parts of the jig, butting its rear end against the stop *a*. The jig is then worked down to the height of the cutter and is

beveled to suit it; as the cutter is hardened, this can be done readily. The jig is now hardened and used to duplicate the cutters. It is made in two parts doweled together in order to cheapen its construction; the act of clamping it in the vise clamps the soft cutter placed in it at the same time, thus obviating the necessity of any clamping device. The filing jig must be made of tool steel. Before the jig can be used, the cutters must be cut down to the correct width for the slots in the mill body, which should be exactly alike to allow the cutters to interchange.

HOLLOW MILL FOR ANNULAR MILLING.

58. Hollow mills can be used with advantage on some classes of work for milling the outside of a cylindrical projection central with a hole passing through it, provided great accuracy is not required. The mill is then made with a central guide pin, as shown in Fig. 29. This pin is to be

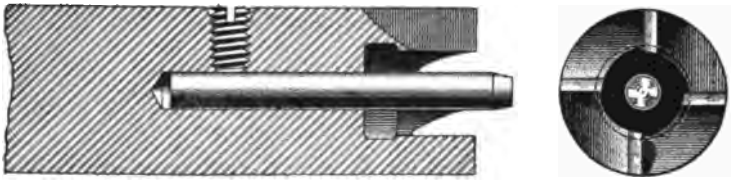


FIG. 29.

hardened at the end and drawn to a spring temper. It is recommended to hold the pin by means of a setscrew to allow ready removal when the mill is to be ground. In order to facilitate the filing of the inside clearance, it is advisable to bore out the rear end of the mill somewhat larger than its inside diameter.

TOOLMAKING.

(PART 3.)

CUTTING TOOLS AND APPLIANCES.

MILLING CUTTERS.

SOLID MILLING CUTTERS.

1. Number of Cutting Edges for Solid Cutters.—Milling cutters up to 6 inches in diameter are usually

TABLE OF CUTTING EDGES FOR MILLING CUTTERS.

Diameter of Cutter.	Cutting Edges.
$\frac{1}{2}$	6
$\frac{3}{4}$	8
1	12
$1\frac{1}{4}$	14
$1\frac{1}{2}$	16
2	18
$2\frac{1}{2}$	21
3	24
$3\frac{1}{2}$	26
4	28
5	30
6	32

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made solid, and above that size they are made with inserted teeth. The number of cutting edges for solid milling cutters intended for general work may be as given in the preceding table, which is believed to conform very closely to average practice.

The cutting edges are generally made with a radial face, as indicated by the dotted lines in Fig. 1 ; the spaces on the circumference may be cut with a cutter that will produce an angle of about 50° between the face and the back of the

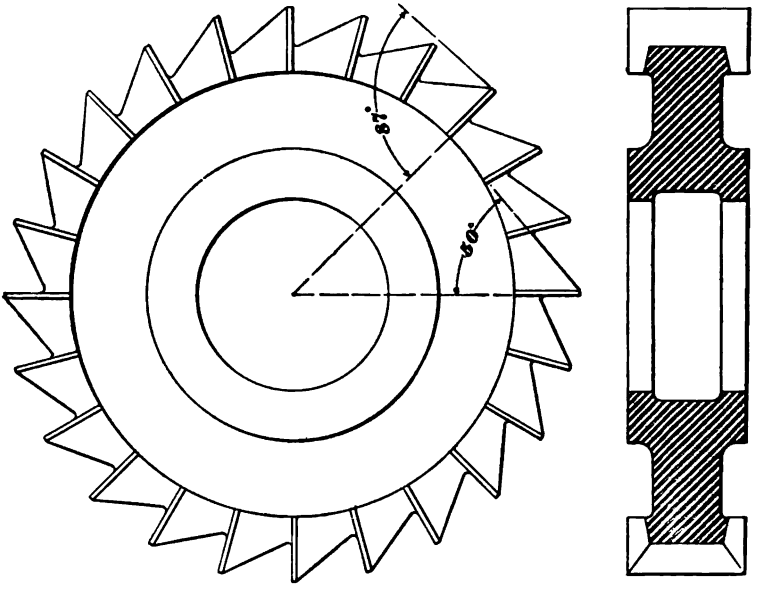


FIG. 1.

tooth. This angle gives an ample depth to the clearance spaces, and, at the same time, gives well-supported cutting edges. The milling cutter used for forming the teeth is run in deep enough to leave the lands from .02 to .04 inch in width, according to the size of the cutter that is being made. If teeth are cut on the sides of the cutter, as shown in Fig. 1, the spaces may be cut with a milling cutter that will produce an angle from 60° to 70° between the face and the back of the tooth. When milling the teeth on the sides,

the index head cannot be left at the 90° mark or at the 0° mark, but must be inclined a little, in order that the cutter may make the lands of equal width. The amount that the index head is to be inclined depends on such variable conditions that computation of it is a difficult problem; in practice, it is most rapidly found by an actual trial. After cutting the teeth, remove all burrs by filing, and harden. The tempering is done to advantage by inserting a red-hot piece of iron in the hole, thus making the cutter softest at the inside. Draw to a good straw color. Since the diameter of the hole is very likely to change in hardening, it is considered good practice to make it slightly smaller, say .004 inch per inch diameter of the hole, and finish by grinding. To reduce the time required for grinding the hole, it may be recessed, as shown in the sectional view of Fig. 1. It is recommended that the sides of the boss be also ground straight and true with the hole.

2. Grinding Milling Cutters.—The teeth are sharpened on a cutter grinder, using the finger of the grinder as a means for obtaining the proper cutting clearance. The teeth may be given a clearance of about 3°; that is, the angle between the face of the teeth and the top of the teeth may be about 87°. If this degree of clearance is given, the teeth will cut freely and the cutter will last well. If more clearance is given, the cutting edges will dull quite rapidly. For grinding the teeth on the side of a milling cutter, a small emery wheel must be used in order to get proper cutting clearance without touching the adjoining cutting edge. The method of grinding milling cutters does not differ essentially from that employed in grinding reamers; the only difference is that the cutting edges, as a general rule, are finished entirely by grinding, no oilstoning whatsoever being done on them.

In order to get the best work out of a milling cutter, it is essential that a cutter grinder be used for sharpening it. It is impossible to grind a cutter by hand so that it will be round. Milling cutters that cut only on their ends when

used for grooving may advantageously be ground so as to be slightly smaller at the rear, say about .01 inch per inch of length. When grinding cutters, it is well to bear in mind that only very fine cuts must be taken, since, otherwise, the temper will be drawn from the extreme cutting edges, which spoils the cutter. The grinding of a cutter is a job that cannot be hurried without inviting disaster to the cutting edges.

3. Helical Cutting Edges.—When making a **helical milling cutter,** more commonly known as a **spiral milling cutter,** choose a helix that will give the cutting edges an angle of about 20° with a plane passing through the axis of the cutter. It does not make any particular difference whether the helix is right-handed or left-handed when the cutter is intended for a machine in which the cutter arbor is supported at the end. However, when used for a machine in which the end of the arbor is free, the helix should be such that the end thrust due to the action of the spiral cutting edges will tend to force the arbor home; that is, if the cutter is right-handed, the helix should be left-handed; if the cutter is left-handed, the helix should be right-handed. In order that there may be no misunderstanding about the terms "right-handed" and "left-handed" when applied to milling cutters, they are here defined as follows: Standing in front of a milling machine with a horizontal spindle, and looking toward the spindle, if the milling cutter revolves in the direction of the hands of a watch, it is a *left-handed* cutter; if it revolves in a direction opposite to that of the hands of a watch, it is a *right-handed* cutter. A right-handed helix, however, is one that, in advancing, turns in the direction of the hands of a watch. A left-handed helix turns in a direction opposite to that of the hands of a watch.

4. Nicked Teeth.—For heavy milling, spiral milling cutters with **nicked teeth** are an advantage, since they break up the chips, which enables a heavier cut to be taken than is possible with an ordinary cutter. A satisfactory way of nicking them is as follows: Gear an engine lathe to

cut a thread having a pitch about equal to the distance between two teeth of the cutter, and with a round-nosed tool cut a half-round thread having a width equal to about one-fourth the pitch of the thread. This is preferably done before the clearance spaces are milled in the cutter. Inserted-teeth cutters with either straight or helical cutting edges, and solid wide cutters with straight cutting edges may advantageously be nicked by cutting a helical groove.

MILLING CUTTERS WITH INSERTED TEETH.

5. Designs.—When milling cutters exceed 6 inches in diameter, the cost of making them of one piece of tool steel

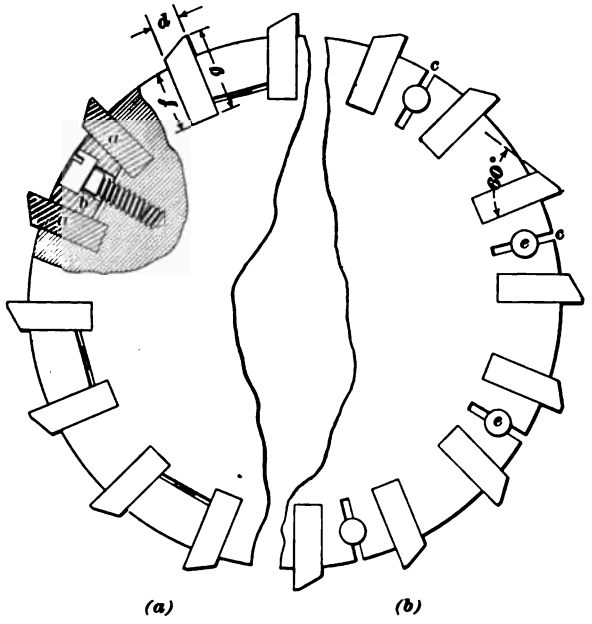


FIG. 2.

becomes rather high; in general, it is cheaper to make them with small teeth that are inserted in a body of cheap material, as cast iron or machinery steel. There is a great variety of designs that will make a satisfactory cutter. The

simplest design is that in which the cutters are fitted to dovetail slots and driven home after hardening. In order to make a good job, the cutters must be very carefully fitted, which makes renewal rather expensive. Again, as the slots must necessarily be dovetailed, they are expensive ones to make. These considerations have led to designs that do not require such close and expensive work, although they are not quite as simple. Two standard designs are shown in Fig. 2. In both, the cutters are rectangular in cross-section. Owing to this shape, the slots can be milled very cheaply, and cutters to fit them can be made at an expense slight in comparison to that involved in making dovetailed cutters. The design shown at (*a*) is one that has been adopted by the Morse Twist Drill and Machine Company, New Bedford, Massachusetts. Rectangular slots receive the cutters *a*, *a*; the body is milled out between every second pair of slots to receive the wedge-shaped piece of steel *b*, which is drawn home by means of the fillister-headed screw shown, and thus locks the cutters. A space is left between the bottom of the piece *b* and the body; this space allows a slight variation in the thickness of the cutters.

In the design shown at (*b*), the metal between every second pair of slots is slotted with a narrow slot, as *c*, *c*. Before cutting the narrow slots, a hole is drilled clear through and reamed "taper" to receive the taper pins *e*, *e*, which are driven in after the cutters are in place and serve to lock the latter. Driving the taper pins out loosens the cutters sufficiently to allow them to be easily withdrawn. This design of cutter is furnished by the Pratt & Whitney Manufacturing Company, Hartford, Connecticut.

6. Helical Cutting Edges. — Inserted-tooth milling cutters may be given helical cutting edges for the same purpose that solid cutters are provided with them. Obviously, if a helical slot is cut into the body, the cutter tooth will also have to be helical in order to fit it. This is a very expensive shape to produce, however, and can scarcely be made with the ordinary machinery to be found in a tool room. For

this reason, straight slots are cut at an angle to a plane passing through the axis, and straight cutters are universally used. Straight cutters set at an angle are open to one serious objection, however, which is that the front face of the cutter is not radial throughout its length, but changes from a front rake at one end to a radial face in the middle and then to a negative rake at the other end. This is shown in Fig. 3, which shows one straight cutter inserted at an angle. In order to bring out the objectionable point more clearly, the diameter of the body has been made rather small. At the end *a*, the face of the cutting edge has front rake, as indicated by the radial line *o c*. At *d*, as indicated by the

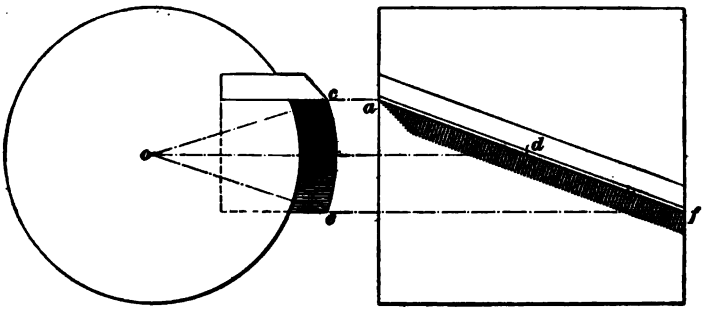


FIG. 3.

radial line *o d*, the cutting edge is radial, changing to a negative rake toward *f*. The amount of negative rake at *f* is shown by the radial line *o e*.

The best way of curing this defect is to mill the cutting face helical with a suitable cutter set to produce a radial face. To allow this to be done, the cutter must either be made thicker throughout, or thickened on the cutting face from beyond the body.

7. Before cutting the slots, select a helix that will give the cutting edges an angle of about 20° with a plane passing through the axis. Gear the milling machine to cut this helix and put the turned blank body in the machine. With a scriber clamped to the milling-machine arbor, scribe a helical line on the surface of the body. This line will then

serve as a guide for setting the index head by trial to the angle that will give a straight slot coinciding closely with the helix. Unless the milling machine is so arranged that the index head swivels on the platen, the slots will have to be cut with an end mill. Many designs of milling machines have a so-called *raising block* to which the index head may be clamped and then swiveled across the platen. If this is the case, the slots can be cut with a regular axial cutter. After the cutters have been inserted into the slots and locked, the milling machine is geared again for the proper helix and the cutting face of each cutter milled helical and radial.

8. Proportions and Number of Teeth.—The number of cutting edges for milling cutters with inserted blades may be about as given in the following table, which is given primarily for the purpose of aiding the toolmaker in selecting a suitable number of cutting edges. As opinions differ considerably in regard to this matter, it must not be expected that all cutters will conform to the table, which is believed to represent average practice.

TABLE OF CUTTING EDGES FOR MILLS WITH INSERTED CUTTERS.

Diameter.	Number.	Diameter.	Number.
6	12	18	35
7	14	20	38
8	16	22	41
9	18	24	44
10	20	26	46
12	24	28	48
14	28	30	50
16	32	32	52

The proportions of the cutters may be about as follows: Referring to Fig. 2, the thickness d of the cutter may be about one-fourth the distance from one cutting edge to the

next one; the depth *g* may be about three-fourths the pitch of the cutting edges; and the depth *f* of the slots may be about fifty-five one-hundredths of the pitch. By *pitch* is here meant the distance from one cutting edge to the other measured along the arc of the circle circumscribed about the cutter. In other words, the pitch of the cutting edges is equal to the circumference of the cutter divided by the number of teeth. The cutters may be backed off with a milling cutter that will give an angle of 60° between the front and the top of the cutter, as shown in the figure. The backing off may be carried forwards enough to leave a land of about .03 inch; after hardening and tempering, the cutting edges are finally given by grinding the assembled mill in a cutter grinding machine, giving a relief of about 3°.

FLY CUTTERS.

9. For work that cannot be classified as repetition work, a **fly cutter** is often of great advantage in milling odd shapes. Having but a single cutting edge, it is quite cheaply formed, even if the shape to be milled is quite complex. If properly made, it can be sharpened quite a number of times without materially changing its shape. Fly cutters are frequently made by filing them to the proper shape; when thus made, it is very difficult to form them so that their shape will not be materially changed by successive sharpenings. If the method given below is adopted, a satisfactory fly cutter will be produced; a further advantage of this method is that the cutter can always be duplicated at small expense.

A fly cutter must not be expected to cut as fast or wear as long as a regular milling cutter; it will reproduce its shape with great exactness, however. It will be found of great advantage in making and duplicating forming tools of irregular contour for the forming lathe and turret lathe.

10. The first step is to make a forming tool, as *a* in Fig. 4, cutting into its front end the shape that the cutter

is to produce. This may be done in whatever way is convenient; it is usually done by filing. This tool is held in the vise of the milling machine and is set at such a height that its top face is level with the center of the spindle. The soft cutter, which, previously, may have been roughly filed to shape, is then inserted in the fly-cutter holder and locked. The machine is now started and the forming tool carefully fed against the revolving cutter, which is thus cut to the shape of the forming tool. The cutter should be fastened to the holder as far inwards as possible; it should not project farther from it than sufficient to just allow the forming tool to clear the holder when fed in enough to cut its full shape. The cutter thus formed has no clearance. This, however, is obtained by the simple expedient of setting the cutter farther out. Grinding a fly cutter thus made will not materially change its shape, as long as the precaution is taken of grinding it on its front face in such a way that the face remains radial. The cutter should be of sufficient thickness to give a radial front face, as shown in the illustration.

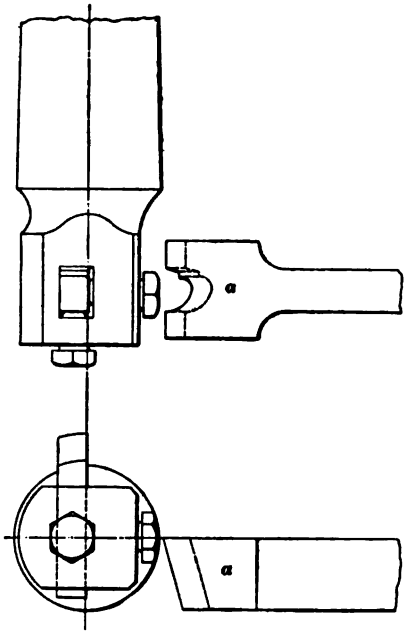
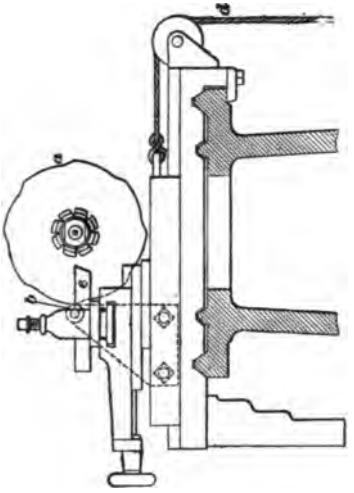


FIG. 4.

FORMED CUTTERS.

11. For milling irregular contours on repetition work done in large quantities, **formed cutters** with teeth shaped to conform to the contour required are in universal use.



These milling cutters are so formed that they can be ground on the face of the cutting edges without changing the shape of the contour. This form can only be given by the aid of special machinery designed for that purpose and not usually found in a tool room. For this reason, it is cheaper, as a general rule, to have formed cutters made to order by shops making a specialty of this work.

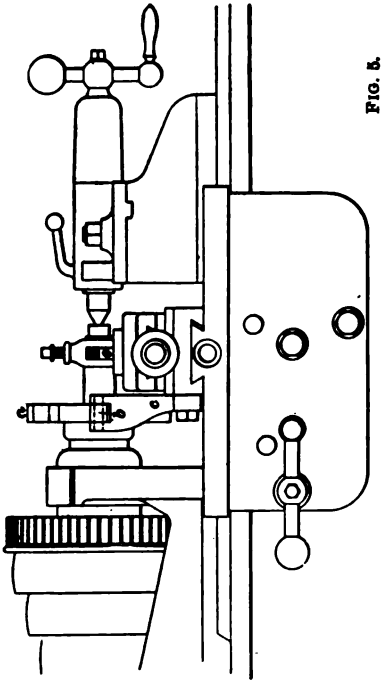


FIG. 8.

12. Backing-Off Attachments. — Should circumstances render it advisable to make formed cutters in the tool room, an engine lathe can be converted temporarily into a **backing-off machine.** The attachments required will not in the least destroy the usefulness of the lathe as a lathe, as will become apparent when the device is studied. For attaching the device, a lathe with a compound rest must be selected. The lathe selected should be very stiff and of ample size; it is recommended that a

20-inch lathe be used in preference to a smaller one. The larger lathe is likely to be much stiffer, which is essential in order to do good work.

The backing-off attachment shown in Fig. 5 is one that is quite simple, relatively inexpensive, adaptable to any lathe having a compound rest, and will do excellent work. Its drawbacks are several: *First*, the amount of clearance for a given size cutter, i. e., the difference in the distances from the center of the cutter to the front edge and the back edge of the land, cannot be changed, being governed by the way the cam is laid out; *second*, the shape of the cam determines the number of cutting edges, which cannot be changed without making a new cam; *third*, using one cam only, the amount of clearance will be the same, irrespective of the diameter of the cutter. From this it follows that a large cutter will have a much smaller angle of relief than a small one. This will be referred to again farther on.

13. The device consists essentially of a cam *a* rigidly attached to a small face plate in any convenient manner. A roller *b*, which is carried by a bracket *c* rigidly bolted to the lower part of the slide rest, engages the cam *a* and is held against it by a heavy weight attached to the rope *d*. The cross feed-screw being taken out of the cross feed-slide, the latter, by reason of the roller engaging the revolving cam, is moved in and out in a manner depending on the shape of the cam. The compound rest is swung around square with the bed, and the forming tool *e* is held in the tool post. It is fed forwards by means of the feed-screw in the upper part of the compound rest. The cutter that is to be backed off is clamped to a short, stiff arbor, which may either form part of the cam, or be fitted to the live spindle and driven by a dog. Before backing off, the cutter must be serrated; it is then clamped on the arbor in such a position that its cutting faces are in the same radial planes as the high points of the cam. This is most readily done by first setting the cam by eye so that one of its high points is on the straight line joining the center of the lathe spindle and the center of

the roller. Then, with the forming tool set to the height of the lathe center, the tool is run forwards until it nearly touches the cutter, which is then rotated on its arbor until a cutting edge is in the same plane as the top face of the forming tool. The cutter is now properly set and is then clamped.

14. A rather simple way of backing off milling cutters was made public by Mr. R. D. Morse in 1899. The rig used

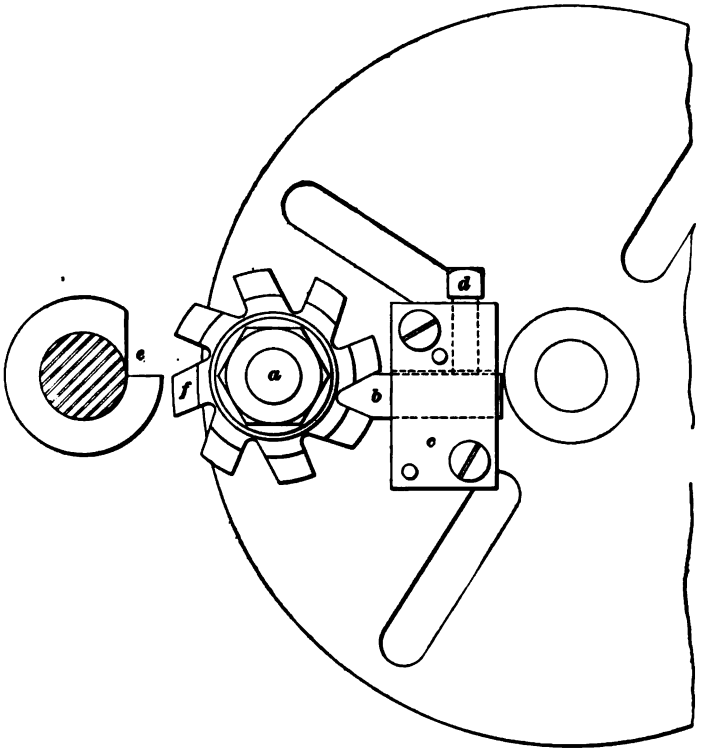


FIG. 6.

recommends itself for its simplicity and cheapness; it is open to only one objection: as the cutting faces are ground away, the shape milled by the cutter changes slightly. The amount of this change is quite small, however, and for many

classes of work may be permissible. The device consists essentially of a stud *a*, Fig. 6, securely screwed into the face plate of a lathe near its periphery. This stud is turned to fit the hole of the cutter, which is clamped to the stud by the nut shown. A pawl *b*, movable longitudinally in a rectangular slot of the bridge *c*, serves to keep the cutter from turning. The pawl is kept from moving by the setscrew *d*. A forming tool, which may be circular as shown at *e*, or flat as was shown in connection with the making of a fly cutter, is held in the tool post of the lathe and fed in gradually until the tooth is formed. After one tooth is formed, as the tooth *f*, the pawl *b* is unlocked and slipped back. The milling cutter operated on is rotated one notch to bring another tooth in position, the pawl is slipped forwards and locked, the cutter clamped again and the forming tool fed in once more. This is repeated until each tooth has been backed off. It will be understood that the milling cutter does not rotate in respect to the face plate, but rotates with the face plate. If a cutter is backed off in this device, it is necessary to cut the notches slightly wider than the lands.

15. Laying Out Cams for Formed Cutters.—Before a cam for a backing-off attachment can be laid out, several factors that influence its design must be known. These are the diameter of the cam, the diameter of the cutter, the number of teeth, and the angle of relief that the cutter is to have. Of these factors, the minimum diameter of the cam is fixed by the design of the lathe it is proposed to use. In general, the cam should be made as small as these considerations permit, since there

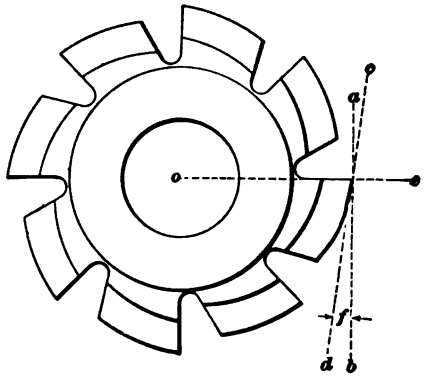


FIG. 7.

is nothing gained by making it large. The diameter of the cutter and the number of teeth being known, the only factor left is the best angle of relief. For wrought iron, cast iron, and steel, it may be made about 8°; for brass, about 10° to 12°. In order that there may be no misunderstanding about the term "angle of relief," it is here defined as the angle *f*, Fig. 7, included between a line perpendicular to a radial line and tangent to the cutting edge, as *a b*, and a line tangent to the curved surface of the tooth at the intersection of the radial line *o e* and the line *a b* perpendicular to it, as *c d*.

16. The preliminary data having been determined, the cam outline is laid off as follows: Referring to Fig. 8, draw

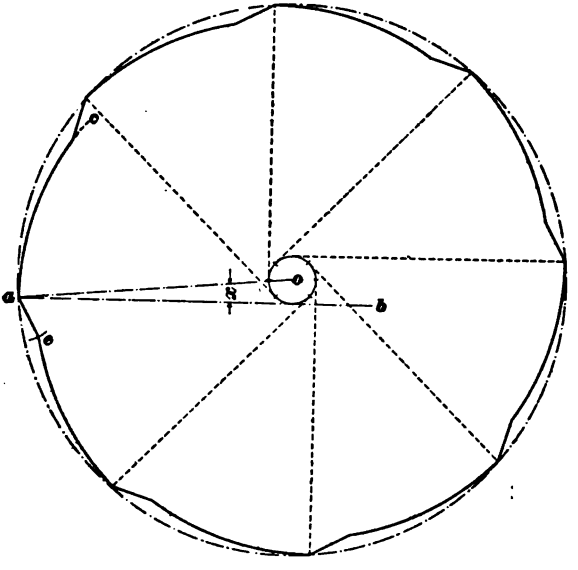


FIG. 8.

a circle having a diameter equal to that of the cam. Divide this circle into a number of equal divisions equal to the number of teeth. From one of these points draw a radial line, as *a o*. Next, multiply the angle of relief determined upon by the outside diameter of the cutter and divide the

product by the outside diameter of the cam. The quotient will be the angle x, which the line $a\ b$ is to make with $a\ o$. Thus, if the angle of relief is to be 12°, and if the cutter is 3 inches in diameter and the cam 9 inches, the angle that $a\ b$ is to make with $a\ o$ is $\frac{12 \times 3}{9} = 4°$. The line $a\ b$ having been drawn, draw a circle about o as a center and tangent to the line $a\ b$. With half the outside diameter of the cam as a radius, and from the points of division on the outer circle, describe arcs intersecting the circle tangent to $a\ b$. With the points of intersection as centers and the same radius, describe arcs, as $a\ c$. Next, with a radius equal to about one-fifth the distance between adjoining divisions on the outer circle and from the points of division, describe arcs intersecting those previously drawn. Join the points of intersection and the points of division on the outer circle by straight lines, as $a\ e$. This will complete the cam outline.

17. Making a Cam for Formed Cutters.—There is a variety of ways in which the cam may be made. One way

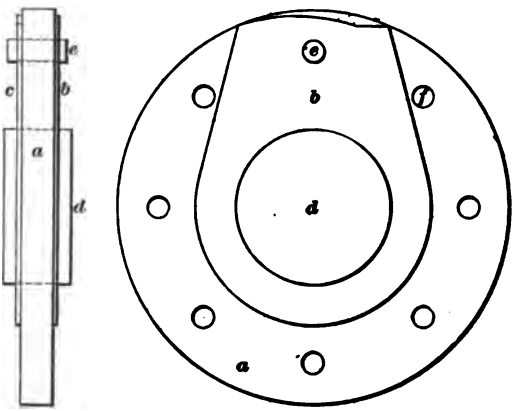


FIG. 9.

that can be recommended, on account of the accuracy that can be obtained by it at slight expense, is shown in Fig. 9. In the illustration, a is the cam; b and c are filing templets secured and held in proper position by the plugs d and e.

The outer ends of the two filing templets are shaped to the proper cam outline and are wide enough to cover one section. They are hardened at the ends as hard as possible, and, when placed in position, the cam is worked down to them. The plug *e* is then withdrawn and the templets revolved to the next hole, as *f*, when the plug is inserted again. This is repeated until the cam is completed.

The first step in making the cam and templet is to bore, turn, and face the cam-blank, which may be made of cast iron. While still on the mandrel on which it has been turned, put it in the milling machine and divide the periphery by fine scriber lines, scribed preferably on the face, into the proper number of equal divisions, using the index head for the purpose. Make a temporary drilling jig shaped about like the templets. Bore a hole to fit the mandrel closely and bevel some part near the end of the jig. Mark a fine radial line on this bevel and drill a small hole, say about $\frac{1}{4}$ inch in diameter, somewhere on the jig at a distance from the center of the large hole equal to about four-fifths the radius of the cam. Then, by placing this drill jig on the mandrel and making the line marked on it coincide successively with the division lines near the periphery of the cam, the hole in the drilling jig can be transferred to the cam by drilling, thus drilling a row of holes equidistant from the center and equally spaced. Next, on a piece of sheet steel, by the method previously given, lay out the cam outline for one section. Carefully file to the line; then bore the hole to fit the plug *d* (or the mandrel, if the work of making the plug is to be saved), and place it on the plug, clamping it to the cam. Drill the hole intended for the plug *e* through the templet, thus using the cam as a jig; then harden its end and from it make an exact duplicate by pushing plugs *d* and *e* through both templets and then filing the second one to the first, or hardened, templet. Harden the second one; put both in place and then file the cam to them.

18. Forming Tool. — The **forming tool** should always be set so that its top face is radial, as indicated in

Fig. 10 by the dotted line. If thus set, it will reproduce exactly the shape given to its cutting edge. The forming tool requires considerable clearance on account of the cutting being done on an arc eccentric in respect to the axis of the milling cutter. The angle included between the face of the forming tool and its top can be found by adding 10° to the angle of relief of the cutter and subtracting the sum

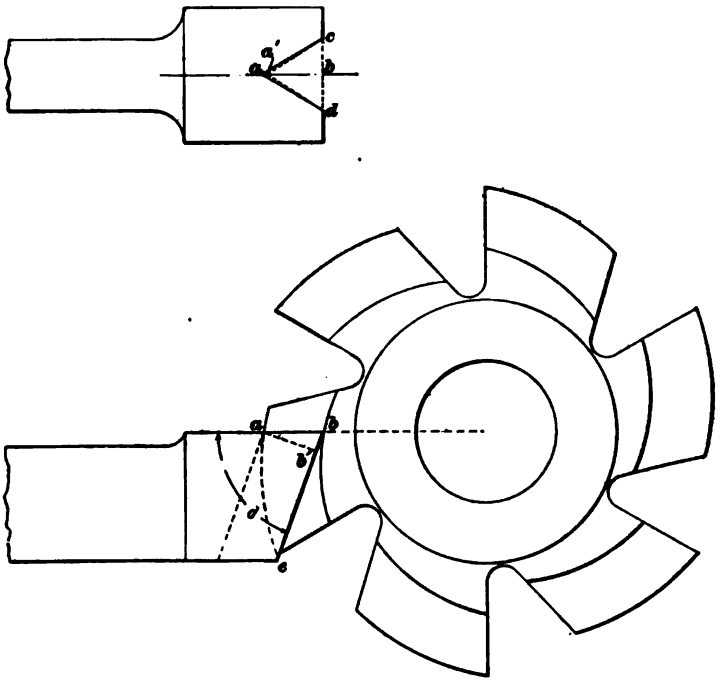


FIG. 10.

from 90°. Thus, if the angle of relief is 8°, the angle *d*, Fig. 10, should be $90°-(8°+10°)=72°$. If the forming tool is given the angle calculated by the method just given, it will have a cutting clearance of 10°, which is considered ample.

When making a forming tool, it must not be assumed that the form can be planed or milled with a tool having exactly

the shape it is desired to produce. That this cannot be done is shown in Fig. 10. The forming tool there shown is of such simple form that it clearly exhibits the difference in shape. Let $a\,b$ be the depth of the form of the forming tool and $c\,d$ its width. Then, the tool that could plane this shape must have a depth $a\,b'$, while its width would be the same as $c\,d$. Now, in the right-angled triangle $a\,b\,b'$, the side $a\,b'$ adjoining the right angle must be shorter than the hypotenuse $a\,b$. Transferring the distance $a\,b'$ to the plan view, and laying off $a'\,b = a\,b'$, we get $c\,a'\,d$ as the shape of the form at a right angle to $b\,e$. In other words, the planing tool or milling cutter used to produce a form as $c\,a\,d$ must have the shape $c\,a'\,d$, which differs somewhat from the shape desired. This difference in shape will vary with the angle d.

19. Theoretically, it is possible to lay out, by the principles of descriptive geometry, the correct shape of planing tool required to cut the form; it is not such an easy matter, however, to transfer this layout to steel, owing to the differences in shape being very small. Hence, in practice, forming tools are made in a different manner.

The forming tool having been planed and squared all over, the form is roughed out and the cutting edge filed to correct shape, filing at a right angle to the top surface. The tool is then placed in the vise of a milling machine or shaper at the proper inclination to give the required clearance, and, with a pointed tool or narrow milling cutter, the clearance is cut in successive steps, using the extreme cutting edge as a guide for setting the cutting tool. By careful manipulation, using a pointed tool or narrow cutter, the forming tool can be cut very close indeed to the required form and will then require very little filing. If thus made, the cross-section of the form will be the same throughout the depth of the forming tool; in consequence of this, the tool can be ground on its top surface without changing its shape, provided the precaution is taken of always grinding square across and without changing the angle d.

WORM-WHEEL HOBS.

20. Designing the Hob.—The **hob** for cutting the teeth of **worm-wheels** is a special kind of a milling cutter. It is practically a duplicate of the worm, except that it is made slightly larger in diameter. It is serrated to form cutting edges, as shown in Fig. 11. The grooves or slots are sunk in deep enough to go below the bottom of the thread, as shown.

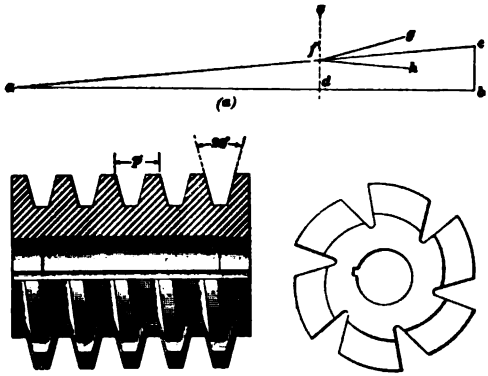


FIG. 11.

Most worms and worm-wheels are made in accordance with the involute system of gearing adopted by the Browne & Sharpe Manufacturing Company, the teeth of the worm having the same shape as the teeth of a rack of the same pitch. The angle included between the sides of the teeth is 29°, or each side makes an angle of $14\frac{1}{2}°$ with a plane perpendicular to the axis of the hob. In this system, the whole depth of the tooth (or space) for the worm is found by multiplying .6866 by the pitch; by *pitch* is here meant the distance between corresponding points of adjoining teeth, as the distance *p*, Fig. 11. The word *pitch* as here used should not be confounded with the term *lead*, which, when used in reference to a worm, implies the distance that one thread advances in a complete revolution. For a double-threaded worm, the pitch will be one-half the lead, and, for a triple-threaded worm, it will be one-third the lead. Knowing the outside diameter of the worm and the

pitch, the diameter across the bottom of the spaces, or inside diameter, is equal to the outside diameter diminished by twice the whole depth of worm-thread. Some toolmakers make the inside diameter of the hob equal to the inside diameter of the worm, while others make it somewhat less. The outside diameter of the hob is found by adding one-tenth the pitch to the outside diameter of the worm. Thus, if the worm is 3 inches outside diameter and .7 inch pitch, the inside diameter of the worm (and of the hob) is $3 - 2 \times .6866 \times .7 = 2.04$ inches. The outside diameter of the hob will be $.1 \times .7 + 3 = 3.07$ inches.

21. Hob-Forming Tool.—The tool for threading the hob and worm should include an angle of 29° and be cut off square across until its width at the end is equal to .31 times the pitch. For the hob under discussion, the end of the tool should be $.31 \times .7 = .217$ inch wide. To find the side clearance required for the tool, draw a line, as *a b* in Fig. 11 (*a*), equal in length to the circumference of a circle having a diameter equal to the inside diameter of the worm. At the one end erect a perpendicular *b c*, equal in length to the pitch. Join *a* and *c* by a straight line. At any convenient point on the line *a b*, erect a perpendicular *d e*, and, from its point of intersection with the line *a c*, draw lines *f g* and *f h* at an angle of 10° to *a c*. Then, the angles *e f g* and *d f h* are the angles that the sides of the thread tool must make with a surface on which the tool is resting in the same position it will occupy in the lathe. For a right-handed worm, the angle *e f g* is that of the left-hand side of the tool, looking on top of the tool from the shank toward its cutting end. For a left-handed worm, the angle *e f g* belongs to the right-hand side of the tool.

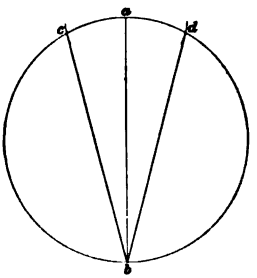


FIG. 12.

22. A 29° angle may be laid out by the following construction, taken from Brown & Sharpe's treatise on "Gearing." In a circle of any convenient size, draw any diameter, as *a b*,

Fig. 12. From *a*, with a radius equal to one-fourth the diameter, describe arcs intersecting the circumference of the circle at *c* and *d*. Draw the lines *c b* and *d b*. The angle included between these two lines is 29°, very nearly. The actual angle given by this construction is 28° 58′; this is close enough for the purpose to call it 29°.

23. Width and Number of Slots.—The width of the round end of the cutter used for serrating the hob may be about .17 × pitch + .12 inch. Thus, for a hob having a pitch of .7 inch, the cutter may be about .17 × .7 + .12 = .239 inch, say ¼ inch wide. The number of slots should be such that the width of land at the bottom of the slots is about equal to the depth of the thread plus .12 inch. To find the number of slots, divide the circumference corresponding to the inside diameter of the hob by the depth of the worm-thread increased by .12 inch plus the width of the cutter. Thus, taking a pitch of .7 inch, the depth of the thread of a worm is .6866 × .7 = .48 inch. Using a cutter ¼ inch wide on the end, the number of slots will be, for an inside diameter of 2.04 inches,

$$\frac{2.04 \times 3.1416}{.48 + .12 + .25} = 7 \text{ slots.}$$

The construction of a hob is influenced by the work to be done and the manner of doing it. If the hob is to be used in an automatic hobbing machine or gear-cutter, where the blank is mechanically rotated, the number of cutting edges may be reduced. If the blank is gashed and the hob depended on for rotating the blank, a greater number of teeth will be necessary, so that at least two teeth may always be in contact with the blank. Hobs work best when the grooves are spirals at right angles to the thread, in place of parallel to the axis of the hob; as in the former case, each tooth has two equal cutting edges instead of one acute edge and one obtuse edge. When the grooves are parallel to the axis of the work, they should be so cut that the cutting faces of the teeth in the center of the hob are radial. Hobs are sometimes hardened without backing off. This will answer

in the case of a hob intended for cutting only one or two gears, but if the hob is to do much work, it should be backed off on all cutting edges. For large worm-wheels, the body of the hob is sometimes made of cast iron or machinery steel and provided with inserted cutters or teeth. A hob must be at least as long as the portion of the worm that engages any of the teeth of the worm-wheel. In some cases where the worm-wheel is to be cut in an automatic machine, a short hob is made for roughing and a longer one for finishing. The teeth of the hob may be plugs inserted and fastened with setscrews. The teeth are sharpened by grinding in the slots with a narrow and rather coarse emery wheel.

DIVIDING CIRCLES AND LINES.

DIVISION OF THE CIRCLE.

24. The toolmaker is frequently required to divide a circle into a given number of **integral divisions.** This may necessitate the making of an original index plate, with holes equidistant from the center and each other and piercing the index plate at a right angle to its surface; or it may require the spacing of notches equidistant around the periphery, or the dividing of the rim by lines or dots into equidistant divisions.

25. There are quite a number of ways in which a circle may be divided mechanically; some of these require the use of scientific apparatus not to be found in tool rooms, while others require nothing beyond the facilities ordinarily at the command of the toolmaker. Some of these latter methods are here explained; each one of them has actually been used and proved satisfactory when reasonable skill was displayed by the workman. The ultimate accuracy attainable by either one of the methods given largely depends on the skill and patience of the toolmaker; neither one of the methods given is here recommended as in general superior to the others. Hence, the choice of method must be governed by

the circumstances of each case, selecting that method which is best adapted to the nature of the job and the facilities at the command of the toolmaker.

DIVIDING BY MECHANICAL CORRECTION OF ERRORS.

26. In Fig. 13, one way of accurately dividing a jig or index plate into a given number of divisions is shown. This method was first made public by Mr. Wm. Baxter in the columns of the "American Machinist." While there is

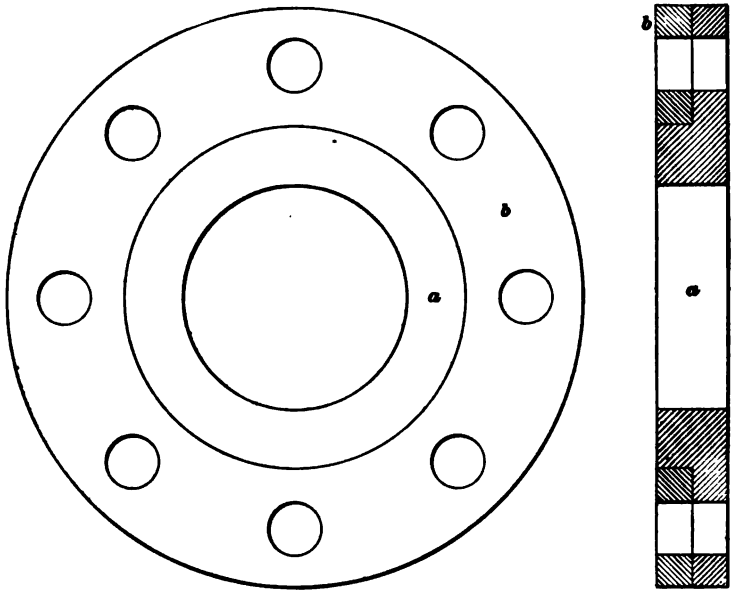


FIG. 13.

little doubt that by its use it is possible to space holes equidistant from the center and each other within an uncommonly small limit of error if sufficient patience is exercised, it cannot be claimed for it that it will also accurately locate the holes on a circle of a given predetermined diameter. Hence, if great accuracy in the diameter of the circle on which the holes are located is an essential condition, the method is not applicable.

27. In the illustration, let *a* be the jig that is to be pierced to receive hardened steel bushings. Make a ring *b* of the same material and approximately of the same thickness as the flange of *a*, fitting the inside of the ring carefully to the projecting rim of *a*. On the surface of the ring *b*, the centers are laid out as carefully as possible, spacing them with a pair of dividers on a scribed circle of the given diameter. The ring and jig is then clamped together and the holes are drilled through both. After the holes have been drilled, a taper reamer and two pins of exactly the same taper are needed. If the holes have been drilled with a $\frac{1}{4}$-inch drill, a reamer about 5 inches long on the cutting edge and tapering from a scant $\frac{1}{4}$ inch at the small end to about $\frac{5}{8}$ inch at the large end, will usually be about right.

After drilling, if the ring *b* be shifted one hole, it will be found that the other holes do not match. To make them match, proceed as follows: Place the ring so that one pair of holes fairly matches and clamp jig and ring together. Ream out this pair of holes until the reamer cuts through *b* and just enters *a*. Drive one of the taper pins lightly into this hole. Ream out a hole opposite the first one and insert the other pin. These two pins prevent any shifting of the ring on the jig in the subsequent operations. Now, ream out all the holes, running the reamer in to the same depth in each one. If it should happen that two corresponding holes are so far out of line as to require the reamer to be run in deeper than in the first hole in order to cut all around the edge of the hole in the jig, ream out until this is accomplished and then go over the holes previously reamed and ream them out to the same size as the last hole. All holes having been reamed, take off the clamps and take out the taper pins; shift the ring *b* one hole ahead, match the holes, clamp the ring and jig together, ream out an opposite pair of corresponding holes, insert the pins, and reream all the holes. Shift one hole ahead again and continue this until all holes match in the ring and jig. If the holes have been located fairly accurate at first, it is rarely necessary to repeat the operation more than six or eight times to bring

them in line. If the holes should match before the reamer has cut all the way through the jig, the operation of shifting one hole ahead and rereaming should be continued until it does.

It is not advisable to run the reamer all the way through in one position of the ring and jig, even though the holes match perfectly; it is much better to remove only a little metal from each hole and then shift the ring again. If it is desired that the holes should be cylindrical instead of conical, the large end of the taper reamer may be made parallel beyond the taper and then run through all the way, removing only a small amount of metal from each hole and then shifting again. This job may be done most conveniently in a drill press. When finished, both ring and jig will be duplicates of each other and both will be correct; the ring may afterwards be used as an original index plate, or may be converted into a duplicate jig. The accuracy that may be obtained by this method is believed to be greater with a relatively thin ring and jig than with thicker ones, and depends more on patience than on skill.

DIVIDING BY CONTACT MEASUREMENTS.

28. Another method that differs considerably from the previous one is shown in Fig. 14. By this method, holes can be located very closely within a given distance from the center; it is believed that after holes bored by this method are corrected again by that shown in Fig. 13, the holes can be spaced within a practically insensible amount of error and thus perhaps the closest approximation to true spacing that is possible by purely mechanical means may be obtained. In the illustration, let *a* be the work that is to be pierced by holes perpendicular to its surface. Let *a'* be a projection intended to center the jig on the work. Then, a circle of approximately correct diameter having been scribed centrally on *a*, divide this circle with dividers into the required number of divisions, and drill and tap at the points of division for a small machine screw of convenient size. Make a

number of steel bushings or buttons having an inside diameter about $\frac{1}{8}$ inch larger than the diameter of the machine screw and an outside diameter of any convenient size. Assemble

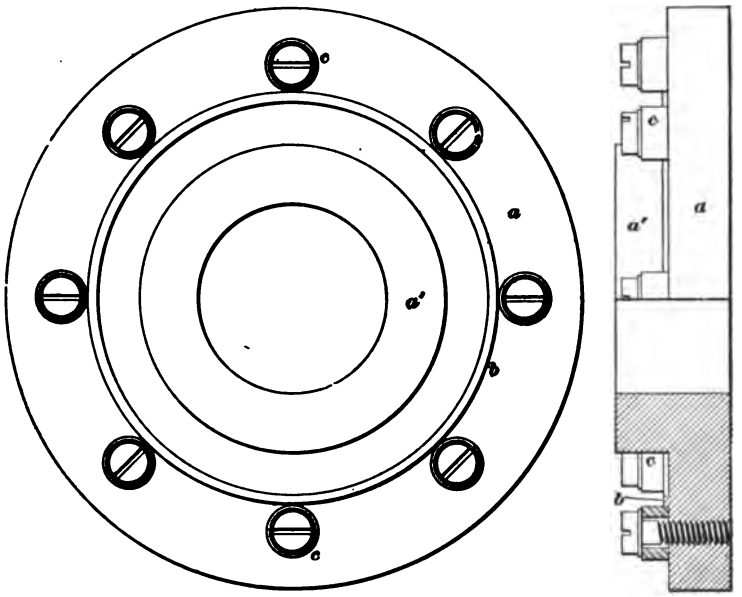


FIG. 14.

these bushings on a long arbor and grind them truly round and to the same diameter. Finish the outside by lapping carefully to insure that all bushings are the same diameter. As far as the diameter is concerned, it need not be any accurate size; the only thing essential is that all bushings have the same diameter.

The height of the bushings is immaterial; it is necessary, however, that the top and bottom surfaces of each bushing shall be parallel and in planes at a right angle to the axis of the bushing. The inside of the bushings does not need to be finished to any extent. The bushings having been made, caliper their size with a micrometer. Subtract this diameter from the diameter of the circle on which the holes are to be located; the remainder will be the outside diameter of a narrow ledge, as *b*, that is turned centrally with *a'*. Evidently,

if the buttons are in contact with the ledge, their distance from the center of the button to the center of the jig will be equal. Fasten the buttons *c*, *c* by means of machine screws, placing a smooth washer that has parallel sides between the head of the screw and each button. Then, each button being in contact with the ledge *b*, adjust buttons about 90° apart until, by calipering over their cylindrical surface, they are shown to be spaced equidistant. Then, adjust the buttons located between those just adjusted until calipering shows all the buttons to be equidistant.

After each adjustment is made, tighten the screws sufficiently to prevent any accidental shifting of the button. The buttons being properly located, mount the jig on a true running face plate and true it until one of the buttons runs true, as shown by a sensitive indicator. Remove this button and bore the hole carefully. In the same manner, bore all the other holes.

In this method, the errors that preclude absolute accuracy are chiefly the error made in locating the buttons and the error in truing up by them. However, with careful workmanship and a fairly sensitive sense of touch, a remarkable degree of accuracy can be obtained; if the spacing is to be still more accurate, follow by the method shown in connection with Fig. 13.

DIVIDING BY CHORD MEASUREMENTS.

29. Fig. 15 shows a method of originating an accurate index plate that was devised and successfully used by the writer. While, for practical reasons, it is limited in its application, there are undoubtedly many jobs on which this method can be used with good results, as far as accuracy and low first cost are concerned. As shown in the figure, there are a number of bars, as *a*, *a*, connected together at their ends by concentric hardened steel bushings *b*, *b*, fitting closely in the holes in the bars. A cylindrical projection on the work is carefully turned down centrally with the axis of the plate until it fits the inside of the bars closely. Then,

if all bars have the same center-to-center distance between their holes, and if the holes in each bar occupy the same relative position in regard to the inside surface of the bars, holes drilled and reamed through the connecting bushings after clamping the device to the work must be equidistant from each other and equidistant from the center of the work. The degree of accuracy attainable by this device, as

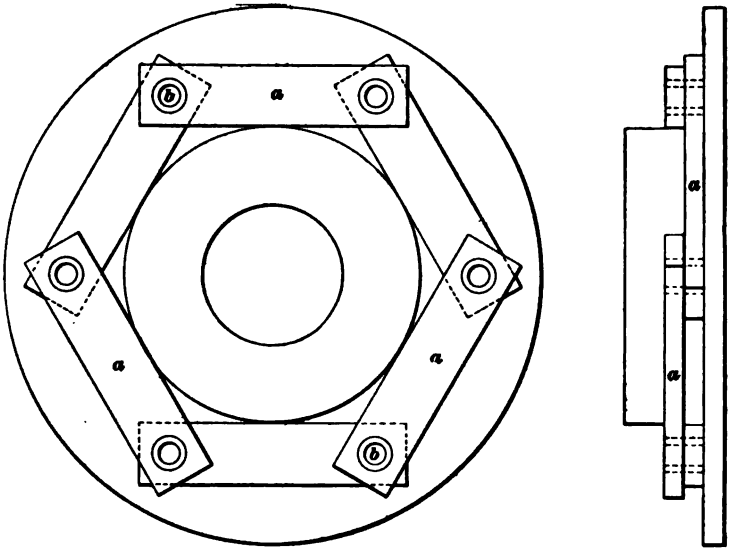


FIG. 15.

far as the division of the circle is concerned, depends on the limit of variation within which the bars can be made alike in their essential dimensions.

A temporary jig may be constructed for the bars; after drilling the holes in all the bars, use a rose reamer that fits very closely into the bushings of the jig and run it through while flooded with oil. The difference in the center-to-center distance of the various bars may thus be well kept within a limit of .0001 inch, and if the work is done at all carefully, this limit of variation need not be exceeded in the relative positions of the holes in respect to the edge intended to bear against the cylindrical central projection of the work. The

limit of accuracy within which the holes can be located on a circle of a given diameter is dependent primarily on the degree of accuracy within which the center-to-center distance of the holes in the bars agrees with the calculated distance. A straight line drawn between the centers of the holes of each bar is the chord of a circle. By geometry, the chord of a circle is equal to twice the sine of half the angle included between the lines drawn from the center of the circle to the extremities of the chord. Then, to find the center-to-center distance of the holes in the bars required in order that the centers will lay on a circle of a given diameter:

Rule.—*Divide 360 by twice the number of divisions into which the circle is to be divided. From a table of natural sines, take the sine corresponding to this angle and multiply it by the diameter of the circle.*

To prevent any mistake in assembling, it is well to finish only one side and edge of the bars by planing. Then, insert all bars the same way in the jig, with the planed edge against the stops and the planed side down; finally assemble with the planed edge inside and the planed side down. The sides of the bars should be fairly parallel; the finished edge of each bar should be scraped to a straight edge.

DIVIDING BY ASSEMBLY OF EQUAL PIECES.

30. While most index plates are provided with correctly spaced holes that receive an axially movable index pin, it may also be made with notches or similar spaces that receive a latch of suitable form. Such an index plate is shown in Fig. 16. It was first employed in connection with some part of the Thorne typesetting machine, where a great accuracy of division was required. As shown in the figure, the circle is subdivided into exactly equal divisions by placing circular disks, equal in number to the number of divisions required, in contact with one another and also in contact with a central circular projection on the index plate. The

index latch pin is then made to suit the approximately triangular space between adjacent disks.

To make an index plate in this manner, make the disks truly circular and of exactly the same diameter by mounting as many as possible, preferably the whole lot if circumstances permit, on an arbor; grind them true and then finish

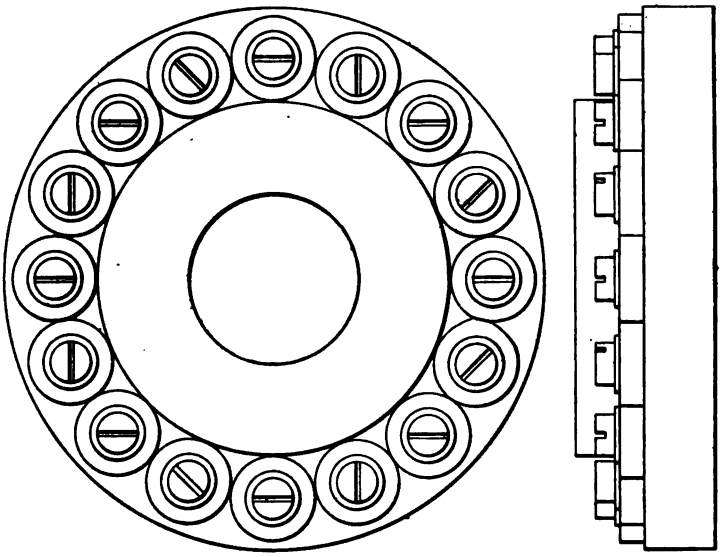


FIG. 16.

by lapping as if it were a plug gauge. The screw holes having been drilled and tapped in the body of the plate, by careful grinding reduce the diameter of the central projection until all disks will touch the projection and one another. If great accuracy is required, the central projection must be ground while the index plate is in its proper place. This will then insure that it is central with the axis around which it rotates. Great care is required not to grind the projection too small; it should be remembered that any reduction in its diameter means that the circumference is shortened more than three times that amount.

DIVIDING BY CORRECTING THE ACCUMULATED ERROR.

31. Fig. 17 illustrates a method of dividing a circle that differs entirely from any of those previously shown. This

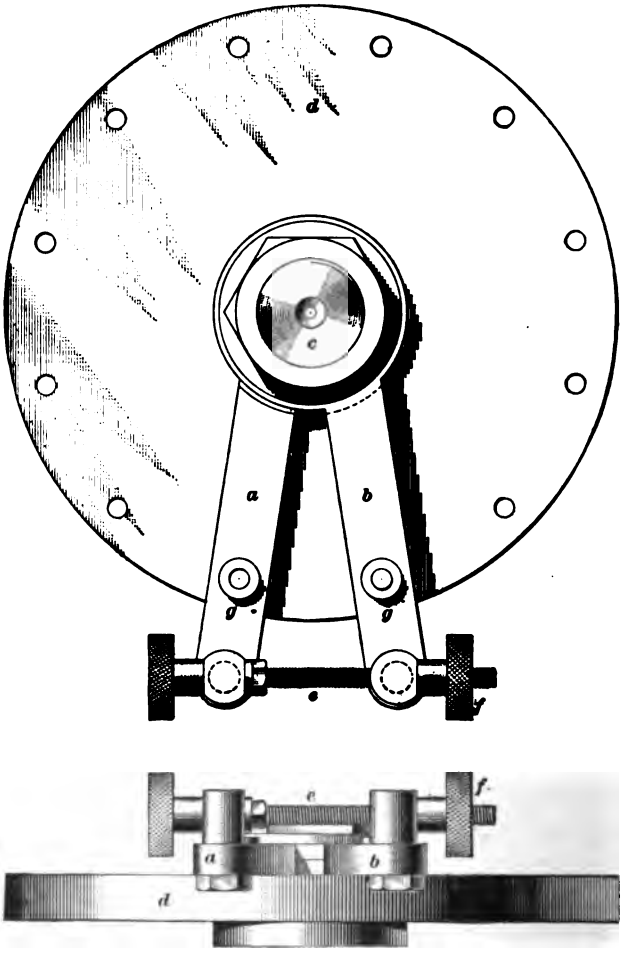


FIG. 17.

method is based on the principle that when successive equal measurements are made, the final error will be the product

of the error of each individual measurement and the number of measurements. Referring to Fig. 17, *a* and *b* are two movable arms free to rotate about a central cylindrical plug *c*, which is closely fitted to a central hole in the work *d*. The angular distance between the arms is adjustable by means of the screw *e*, made with a very fine pitch of thread. A locknut *f* placed on the screw *e* prevents any motion of the arms after adjustment. Each arm is pierced with a hole that receives hardened steel bushings *g*, *g*; these bushings must be exactly the same distance from the center of rotation of the arms, and, at the same time, their distance from the center must be equal to the radius of the circle on which the holes in the work are to be located. The bushings are made a nice fit in the arms; the hole through the bushings must be exactly concentric with their outside.

To use this device, the center-to-center distance between the holes is first calculated by the rule given in Art. **29**; plugs are then inserted in the bushing holes, and, by measuring over them or between them with a vernier caliper or micrometer, the center-to-center distance of the holes in the arms is adjusted by means of the screw *e* to coincide as closely as circumstances permit with the calculated distance. The bushings are then inserted and one hole is drilled and reamed through the work. A closely fitting plug is pushed through the bushing into the hole just reamed and the second hole is drilled and reamed. The plug is now withdrawn and the device shifted until the plug can be inserted into the last hole. Another hole is now put through the work and this operation is continued until all holes have been drilled. It will now be usually found that the center-to-center distance between the last hole and the hole first drilled differs from the center-to-center distance of the other holes. If it is less, it shows that the arms are too far apart; if it is more, they are too close together. Readjust the arms, remembering that the error has been multiplied; substitute new bushings with a larger hole and ream all the holes. Continue until the center-to-center distance between the first and the last hole is equal to that of all the other holes.

32. The device shown may be varied to suit circumstances. Thus, it may readily be adapted for drilling radial holes equally spaced around the periphery; or it may be used for graduating the face or the periphery, substituting a slide carrying a marking point for the bushing in one arm and placing a microscope with cross-hairs in the place of the other bushing. In that case, a suitable clamping device must, of course, be added. Knowing the principles involved, numerous modifications will suggest themselves upon reflection.

DIVISION OF LINES.

MECHANICAL DIVISION.

33. The most familiar and most common form in which this problem presents itself to the toolmaker is the equidistant spacing of holes that are located on a straight line. One way of locating the holes is by means of steel buttons

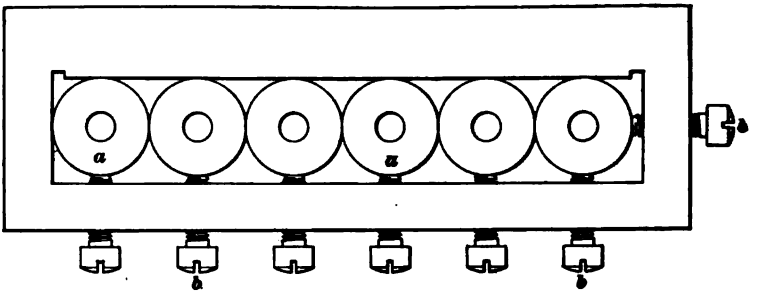


FIG. 18.

located in a straight line by being brought in contact with a straightedge and placed at the correct center-to-center distance by contact measurements. Another method that will produce very accurate results and is applicable to a great many different jobs is shown in Fig. 18. A number of hardened steel disks, as *a*, *a*, equal in diameter to the center-to-center distance of the holes, are put into a frame and held in contact with one another and with one side of the frame that forms a straightedge by means of the

setscrews *b*, *b*. Evidently, if the disks are pierced by holes central with their outside, and if holes are drilled and reamed through these disks, these holes will be equidistant and on a straight line.

The accuracy in spacing attainable depends primarily on the accuracy in diameter of the disks and the concentricity of the holes in them, while the accuracy within which the holes lie in a straight line depends on the stiffness and on the accuracy with which the straightedge of the frame is formed. The error in the center-to-center distance of the end holes is evidently the product of the error in diameter of a single disk and the number of disks. With proper facilities, there should be little trouble in making the diameter of the disks equal within an insensible amount of variation; and as the diameter need not vary more than .0001 inch from the true diameter, and while it is feasible to make the holes in the disks concentric with the outside within a negligible amount of variation, it follows that the total error between the end holes should be very small indeed.

When a rather large number of holes are required, this device may be made to include, say, six holes and then be shifted forwards, being centered by a pin passing through the first disk into the last hole. If this is adopted, the whole device must be shifted along a straightedge of sufficient length; the outside of the frame must then be finished parallel to the line passing through the centers of the disks.

34. Another method of mechanically spacing holes in work is to locate the first hole by means of a center-punch mark or a steel button, the work being mounted on the face plate of a lathe. A straightedge is then clamped to the face plate in contact with one side of the work. After the first hole is finished, a vernier depth gauge or a special micrometer head is clamped opposite the end of the work and the distance to the work measured. The clamps on the work are then loosened and the piece shifted the proper distance along the straightedge, the distance being measured by the vernier or micrometer. The work is again

clamped and the second hole finished. Fig. 19 shows a handy form of special micrometer that may be used for such work.

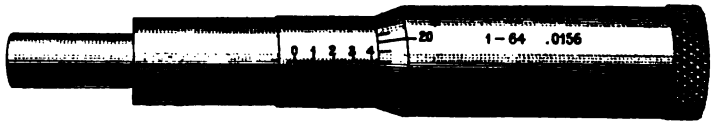


FIG. 19.

Holes in work can also be spaced by mounting the work on the table of a milling machine and obtaining the spacing, either vertical or horizontal, by means of the graduated dials on the feed-screws.

DIVIDING BY CORRECTING THE ACCUMULATED ERROR.

35. Fig. 20 shows a modification of the method explained in connection with Fig. 17 for dividing a circle. In this case, the problem is to subdivide the distance between two holes into an equal number of divisions. The movable arms of Fig. 17 are here replaced by a block with movable slides *a* and *b*, which carry the bushings. In its simplest form, the device is without any adjusting screws; for refined

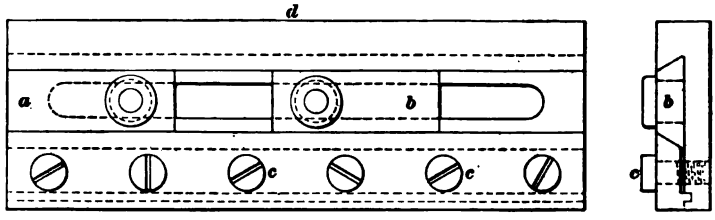


FIG. 20.

work, these screws are needed, and they may be applied either to one or to both slides, as desired. By tightening the screws *c*, *c*, the slides and block are locked together without disturbing the center-to-center distance of the bushings. The device must be used in conjunction with a straightedge if the holes are to be on a straight line, or a curved guide of suitable curvature if the holes lie on a circular

arc. The side *d* is intended to slide along the straightedge or the curved guide and must be made to suit.

Suppose that the distance between two holes is to be subdivided by a number of equally spaced holes that are required to lie on a straight line. A straightedge of sufficient length is clamped to the work in such a position that when the device is in contact with the straightedge, a closely fitting plug will pass through the bushings into both holes when shifted from one to the other. The slides are then set about the required distance apart and locked. A plug is pushed through one bushing into the hole in the work and a hole is drilled and reamed through the other bushing. The device is then shifted along and the other holes are put through the work.

When the last hole has been reamed, the distance between it and the end hole is most likely to differ somewhat from the center-to-center distance between the bushings. The difference is then split in accordance with the direction in which observation showed the center-to-center distance to vary and the operation of reaming is repeated. This process is repeated until plugs passing through both bushings will enter the end hole and the one adjoining it. When making a device as shown in Fig. 20, it is to be observed that it is essential to have the centers of both bushings at the same distance from the edge *d* when it is required that the holes in the work shall be in a straight line.

GAUGES AND GAUGE MAKING.

GAUGES.

CLASSIFICATION OF GAUGES.

1. Most of the measurements made in the machine shop consist of determining linear distances, or of the measuring of angles; hence, only gauges intended for such work will be considered in this section. A **gauge** may briefly be defined as any standard of comparison. Gauges may, according to their purpose, be divided into two general classes—*reference* and *working gauges.*

2. Reference gauges are gauges that represent either an accurate subdivision of the ultimate standard of reference, or some arbitrary size or shape adopted for some purpose and required to be preserved. The ultimate standard of reference may be the standard bar for the metric system or the standard bar for the imperial standard yard. Reference gauges are commonly kept for testing other gauges and hence are often called **master gauges.** They are of many shapes and forms, which depend on the purpose for which they are intended. Among the more common forms may be mentioned the standard end-measuring pieces made by the Pratt & Whitney Company, and the standard disks and end-measuring pieces made by the Brown & Sharpe Manufacturing Company. Among the reference gauges of a more special class may be mentioned the *taper gauges*, which show the exact taper of the different Morse taper shanks for twist

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drills; the master gauges for these are, of course, in the possession of the Morse Twist Drill Company. In a broad sense, the ultimate standard of reference in the United States, which consists of the metric bar in the possession of the Government, is a reference gauge, as are also bronze No. 11 and Low Moore Iron No. 57, which were originally brought to this country to represent the English standard yard.

3. Working Gauges.—There are two general classes of **working gauges** used in the shop—first, those that represent an integral or fractional subdivision of the ultimate standard of reference, whether it be the imperial yard or standard meter bar; second, those that are intended for preserving some special form and are used for duplicating work. To the second class belong all taper gauges and an infinite variety of special gauges for various irregular parts, such as occur in the manufacture of guns, sewing machines, and other similar articles.

4. Definite and Limit Gauges.—Gauges may also be subdivided into *definite gauges* and *limit gauges.* **Definite gauges** are those that establish a certain linear or angular dimension, but do not indicate any variations from the standard of the gauge. A **limit gauge** really consists of two definite gauges that represent the limits within which the piece in question will pass inspection. Evidently a piece of work to pass inspection of the limit gauge must be of such size that it is smaller than the large gauge and larger than the small gauge of the pair.

ACCURACY ATTAINABLE IN GAUGE WORK.

5. Limits of Accuracy.—The definite gauges in most common use are **plug and ring gauges, snap gauges, end-measure rods,** and **taper gauges.** Of these gauges, the first three named establish definite linear dimensions, and the last named establishes an angular dimension.

Definite gauges in general, and also some limit gauges, cannot usually be made without suitable measuring instruments. The kind of measuring instrument to be employed naturally depends on the accuracy with which a size is to be established. In general, the limits of accuracy that may be obtained by the aid of the various measuring instruments are as follows:

1. Using a graduated standard scale, made by a reputable maker, that has its graduations cut in a dividing machine and setting calipers to it, the limit may be placed at .002 inch; that is, the size established may be .002 inch above or below the true size, giving a total variation of .004 inch.

2. Using a vernier caliper, if made by a reputable maker, the total variation need not exceed .001 inch. Remember that the total variation is twice the limit of accuracy.

3. By the aid of a good micrometer kept in first-class order and tested frequently by standard end-measure pieces or reference disks, gauges can be made in which the total variation is within .0001 inch.

4. When the total variation is to be less than .0001 inch, a micrometer is not reliable enough, and recourse must be had to a standard bench-measuring machine in which a contact piece takes the place of the sense of touch of the toolmaker. With such a machine, work can be measured within a limit of accuracy of .00002 inch, or a total variation of .00004 inch. This may be considered ordinarily as the commercial limit of accuracy; it is rarely required for gauges other than reference gauges.

5. Measurements closer than those possible with a bench-measuring machine are made by means of a comparator. Work of this class is outside of the legitimate domain of the toolmaker and comes within the realm of the scientist, since it cannot be justly classified under the heading of commercial work.

6. Needless Accuracy in Gauges.—In gauge work, the toolmaker must guard against needless accuracy, since the cost of gauges is increased at an enormous rate with

every reduction in the limit of variation. The purpose that the gauge is intended for will usually indicate the permissible limit of variation, and thus, by the exercise of judgment, allow a proper method of making it to be chosen. This in turn will allow gauges to be produced that are not only "good enough" but also reasonable in first cost. For instance, a gauge intended for testing the accuracy of a micrometer naturally needs to be accurate in itself, within the commercial limit of accuracy; while a gauge intended for trying the bore of a large steam-engine cylinder, say, 40 inches in diameter, would usually be accurate enough for the purpose if it varies not more than .01 inch from its true dimension. Likewise, a gauge intended for the blacksmith, who, on medium-sized work, would consider it very good indeed if he works to within $\frac{1}{16}$ inch variation, would be needlessly accurate if made closer than $\frac{1}{64}$ inch to its true size.

Sometimes it is rather difficult to decide on how close a gauge must agree with its nominal size; in that case, the toolmaker must use his judgment. For instance, suppose that some part of a job is to be turned cylindrical and to fit a hole in some other piece, the two pieces of work being done by different men working to gauges. Then, while it is of paramount importance that the gauges used by the two men agree with each other, this does not necessarily imply that the actual size of the gauges must agree with their nominal size within the utmost degree of refinement. Judgment alone can determine the comparative accuracy required.

MATERIALS USED FOR GAUGES.

7. Hardened-Steel Gauges.—The material most commonly used for gauges is **tool steel,** although for some work machinery steel is "good enough." The treatment of tool steel for gauge work depends somewhat on the accuracy required and the hardness of the gauge. When a gauge made of tool steel, hardened all over, and probably clear through, or nearly so, is finished to an accurate size immediately after hardening, it has been observed that, frequently,

there is a gradual change of size or shape taking place, which, in the course of time, may cause a sensible deviation. This change of shape is ascribed to a rearrangement of the molecules of the steel, whose former arrangement has been violently disturbed by the hardening process. Fortunately, this change of shape, which, according to observation, lasts for about a year, is not very large, rarely exceeding .0005 inch per inch diameter, hence it need not be taken into account for any but very accurate gauges. For reference gauges made within a limit of variation of .00002 inch, it must be taken into account if the nominal size or shape of the gauge is to be preserved. The usual way is to rough out the gauge directly after hardening to within a small amount, say, .002 inch per inch diameter for a plug gauge, and then allow it to "season," or "age," as it is called, for about a year before finishing it to size.

Personal observation has led us to believe that this seasoning process can be greatly hastened by drawing the hardened gauge to a straw color after it has been roughed out. Undoubtedly, a change takes place even after this, but we believe the amount is so small as to be insensible, and hence negligible for commercial work. As a matter of course, this method of seasoning steel leaves the gauge softer, and hence it will wear faster. Whether this is a matter of sufficient moment to prohibit the use of this method, everybody must decide for himself.

8. Soft Steel Gauges.—Reference gauges that are rarely used are often left soft; they are then made from well-annealed tool steel, which does not seem to change a sensible amount with age. Machinery steel, if well annealed in case any forging has been done in making the gauge, will keep its shape and size very well; being much softer than tool steel, it will naturally wear much faster. Gauges that are made from tool steel, but hardened only in parts, do not seem to be affected much, if any, by the "aging," provided, of course, that the hardening extends over but a very small part of the gauge.

GAUGE MAKING.

PLUG AND RING GAUGES.

9. Making a Plug Gauge.—To make a **plug gauge,** turn down a piece of well-annealed tool steel on centers of liberal size, making a grinding allowance of .01 inch up to ¼ inch diameter, .02 inch up to ⅝ inch diameter, and .03 inch up to 1¼ inches diameter. Above that size, .04 inch should prove ample. Flute or nurl the shank, then turn a groove, as *a*, Fig. 1, with a half-round tool, at a distance from the



FIG. 1.

end sufficient to come clear of the countersink. Turn the groove deep enough to leave the diameter of the neck about $\frac{3}{32}$ inch for a ¼-inch plug gauge, and ⅛ inch for sizes up to ½ inch. For sizes up to ¾ inch, it may be $\frac{3}{16}$ inch in diameter, and ¼ inch for sizes up to 1¼ inch. For sizes above this, leave the neck about ⅜ inch in diameter. The distance *b* may be about one-tenth the diameter of the gauge, plus .2 inch. Harden all over and then grind in a grinding machine to within a small amount of the finished size. Now, let the steel season by age, or temper it to hasten the seasoning. Then grind to within .001 inch of the finished size, and as truly cylindrical as possible. Finish by lapping with the finest flour emery, using a speed lathe for the sake of convenience, and a suitable lap.

The process of lapping naturally heats the gauge considerably; if it is measured while hot, it will be below size when it has cooled to the normal temperature, owing to the contraction of the steel in cooling. For this reason, the gauge must be cooled to the temperature of the room before it is

measured, if any degree of accuracy is required. To cool it, insert it in a bucket of water that has been in the room for an hour or more, leaving it in the bucket long enough to cool down to the temperature of the water. Repeat the lapping until the gauge is the correct size, within the limit of accuracy determined necessary. All measuring must be done on the cylindrical part of the gauge itself, but never on the disk at the end. In sliding the lap back and forth while lapping, the lap is sure to cut faster at the extreme end of the gauge, which is therefore ground slightly tapering, as careful measuring will show. In order that the gauge may be straight throughout, the disk is formed at the end and then broken off after the gauge is lapped to size. To finish the end nicely, grind it off square in a grinding machine, holding the gauge in a chuck.

10. Lap for Finishing Plug Gauges.—The lap may be made in various ways. A very satisfactory construction is shown in Fig. 2. The lap proper consists of a

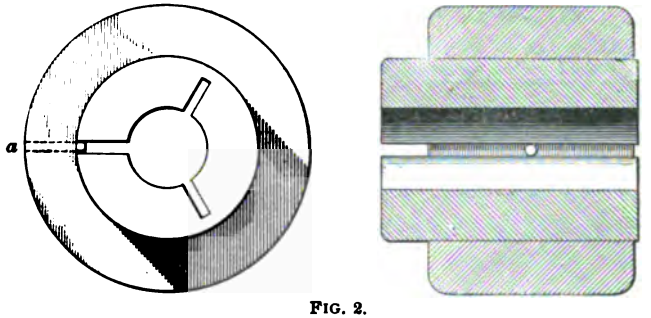


FIG. 2.

ring bored parallel inside and to a diameter about .001 inch larger than the outside diameter of the gauge. The outside of the ring is turned tapering on a taper of $\frac{1}{8}$ inch per foot; it is fitted to a collar somewhat shorter than the lap. The lap is split by three cuts, two of which terminate at a short distance from the exterior surface. The third cut is carried clear through. Evidently, driving the lap into its collar closes the lap in. The most satisfactory material for it is

close-grained cast iron. In the lap shown, the friction between the collar and the lap is usually sufficient to prevent the lap from turning in its collar. If desired, a small pin, as *a*, may be inserted. The length of the lap should not be less than three times the diameter of the gauge. With the construction shown, the lap is closed in practically uniform throughout its length; this is necessary in order to produce good work.

11. Making Large Plug Gauges.—Large plug gauges may be made in two parts. The body may then be made of machinery steel, and a hardened tool-steel bushing that has been ground on the inside after hardening may be forced over the body and then ground and lapped to size. The bushing being rather thin, the change in shape or size while seasoning is infinitesimal. The inside of the bushing may be ground out slightly tapering, say on a taper of $\frac{3}{16}$ inch per foot; the body should then be ground to fit very nicely. Owing to the bushing being hard, great care must be exercised not to drive it on too much, since it is easily split. Have both body and bushing perfectly clean and free from oil before driving the bushing home. Very little driving will then hold the bushing so tight that it cannot be loosened by any reasonable usage.

12. Classes of Ring Gauges.—**Ring gauges** may be made in two ways: They may be made of a solid block of tool steel hardened all over, or they may have a body of machinery steel into which a hardened tool-steel bushing has been forced. Each of these methods has its own advantages and disadvantages. As far as the solid-ring gauge is concerned, it is cheaper in first cost, and not liable to be indented by accidental blows; on the other hand, it is liable to crack in hardening, will change in shape or size while seasoning, and is worthless when worn. The second method of construction mentioned is slightly more expensive; this, however, is offset by the comparative absence of change in seasoning and the fact that when slightly worn it can be restored to its former size by driving the bushing home,

which is made slightly tapering on the outside for this purpose. Furthermore, when worn so as to be unserviceable, a new bushing can be made at less cost than a new solid-ring gauge can be made. Knowing the advantages and disadvantages of each method, the toolmaker must decide for himself which one to adopt.

13. Making a Solid Ring Gauge.—To make a solid gauge, use a piece of annealed tool steel long enough to give the form shown in Fig. 3 (*a*). Make the height *a* of the

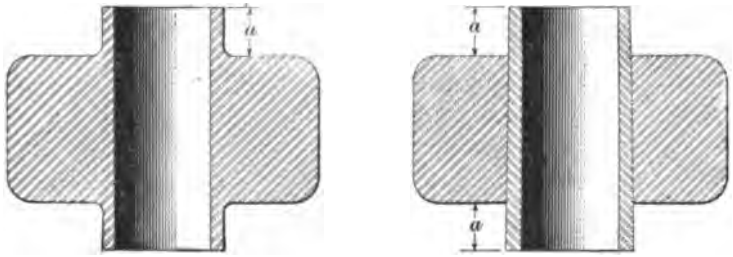


FIG. 3.

projection about one-tenth the gauge diameter plus .2 inch. Make the diameter of these projections from $\frac{1}{8}$ to $\frac{3}{16}$ inch larger than the gauge diameter, and leave an ample grinding allowance on the inside. Finish the outside, stamp the size on the ring, and then harden. For the larger sizes, now grind the inside to within a small fraction of the finished diameter if an internal grinding device is available; if not, grind out by lapping in the same manner as must be done for sizes too small to admit of grinding. Then season and finally bring to the finished size by lapping, using the plug previously made as a gauge. Great care must be taken to have plug and gauge at the same temperature while trying the fit; also, both the plug and ring must be absolutely free from the abrading material used for lapping. The operation of lapping will leave the ends of the gauge slightly bell-mouthed; when the plug just commences to enter at either end, it will show the toolmaker that the ring gauge

is lapped very nearly to the finished size. For the final lapping, the very finest of flour emery must be used with a copious supply of oil.

The fit of the plug in the ring should simply be perfect. It should be so perfect that when the temperature of the plug is raised to blood heat by holding it in the hand for a few minutes, it will not enter the ring gauge, which is here supposed to be at a temperature of about 70°. In trying the fit, try to enter the plug by a combined sliding and rotary motion; should the plug stick, do not drive it out under any circumstances, but heat the ring gauge a little, which will quickly expand it enough to allow the plug to be withdrawn by hand. If the plug be driven out when stuck, there is a liability of badly scoring both the plug and the ring gauge. When the ring gauge has been lapped to a perfect fit, the projections at each end are ground off flush with the faces. The hole will then be perfectly straight.

14. Making an Inserted-Bushing Ring Gauge. When making a ring gauge with an inserted bushing, the machinery-steel collar may be made first, finishing it all over. The central hole is to be bored and, preferably, ground afterwards slightly tapering, say, about $\frac{3}{16}$ inch per foot, making it about one-tenth the diameter plus .1 inch larger than the size of the ring gauge. Turn and bore the tool-steel bushing, leaving a grinding allowance on the inside and outside. Make the bushing long enough so that when driven home it will project at least one-tenth the gauge diameter plus .2 inch on each side. Harden the bushing and then grind or lap the inside true and round to within, say, .001 inch of the finished size. Place the bushing on a true running arbor and grind the outside to fit the tapering hole in the collar. Remove from the arbor and drive the bushing home in the collar, driving lightly. Finish the gauge to size by lapping it to fit the plug. Grind off the projecting ends of the bushing and finish by polishing, if a fine external finish is desired. A slight amount of wear can be taken up by driving the bushing farther into its hole.

15. Laps for Ring Gauges.—There are various ways in which the lap for lapping the hole true and straight may be made. Many toolmakers believe that the form shown in Fig. 4 makes the most satisfactory lap for this work. It consists of a mandrel turned tapering about $\frac{1}{8}$ inch per foot and a split shell bored to fit the mandrel. Cast iron will make a very satisfactory material for the shell, which is turned about .001 inch below the size of the hole in the gauge. It is most conveniently turned on its own arbor, being split after turning. It is advisable to cut two shallow

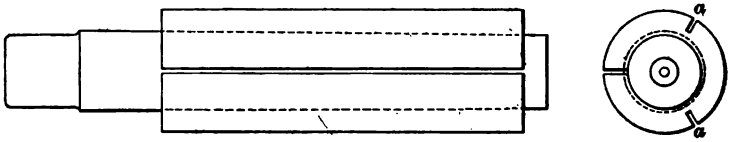


FIG. 4.

slots, as *a*, *a*, into the shell; these, in conjunction with the slot that splits the shell, will act as reservoirs for the abrading material and oil. The depth of these two slots should be greatest for a thick shell; they will then facilitate the expanding of the lap, which is done by driving it farther on the mandrel. If the lap has been used for roughing out the hole, and has in consequence been expanded considerably, it will be somewhat out of round. Hence, it is recommended that before the hole is lapped to final size, the lap should be ground true and round in a grinding machine. The lap simply *must* be round in order to lap the hole true. The length of the shell should not be less than twice the height of the ring gauge; it can advantageously be made three times the height.

16. Proportions of Plug and Ring Gauges.—There is no recognized standard of proportions for plug gauges and ring gauges. To aid the toolmaker in selecting dimensions, the proportions given by the following formulas may be used. In these formulas, *d* is the diameter of the plug gauge.

Length of cylindrical part of plug	$= 1.8d + .4$ inch.
Length of handle	$= .5d + 1.5$ inches.
Diameter of handle	$= .5d + .2$ inch.
Height of ring gauge	$= .9d + .3$ inch.
Diameter of ring gauge	$= 2.2d + .5$ inch.

These formulas should not be used for plug and ring gauges exceeding 3 inches in gauge diameter.

EXAMPLE.—A 1-inch plug and ring gauge is to be made. About what proportions may be adopted ?

SOLUTION.—Applying the formulas given, we get: Length of cylindrical part $= 1.8d + .4$ in. $= 1.8 \times 1 + .4$ in. $= 2.2$ in.; length of handle $= .5d + 1.5$ in. $= .5 \times 1 + 1.5$ in. $= 2$ in.; diameter of handle $= .5d + .2$ in. $= .5 \times 1 + .2 = .7$ in.; height of ring gauge $= .9d + .3$ in. $= .9 \times 1 + .3$ in. $= 1.2$ in.; diameter of ring gauge $= 2.2d + .5$ in. $= 2.2 \times 1 + .5$ in. $= 2.7$ in. Ans.

In a plug gauge and a ring gauge, the only essential sizes are the gauge sizes; all other dimensions are approximate and close enough if made within $\frac{1}{32}$ inch of the dimensions adopted. It is a waste of time and an evidence of misdirected skill to take much pains to work closer as far as these dimensions are concerned.

17. Limit of Variation for Limit Gauges.—Plug and ring gauges establish a definite size; by trying them into a hole or over the shaft, they show if the hole or shaft is the correct size. They do not show, however, the amount of variation from the true size, nor whether the variation in the size of the hole or the shaft is sufficient to prevent one from fitting the other with the requisite degree of accuracy, or whether they will go together at all. There is very little work indeed that requires to be as close a fit as a plug gauge into its ring gauge; in nearly all work, quite an appreciable deviation from this degree of fit is permissible. Naturally, the amount of deviation varies with the circumstances of each particular case. Furthermore, to finish a shaft, and bore a hole to receive it, to an accurate size is a very expensive job, and rarely necessary. Then, in order to prevent needless accuracy in finishing two pieces of cylindrical work

that are to fit each other, **limit gauges** are employed. Thus, if a shaft is to be 1 inch in diameter, and it has been decided from previous experience and observation that the fit will be close enough if there is .002-inch variation between the size of the shaft and the size of the hole, two sets of plug and ring gauges differing from each other by the allowable variation may be used as limit gauges. One of the sets would usually be made one-half the allowable variation larger than the nominal size, and the second set would be made just as much smaller. In using the plugs, the smaller plug must enter the hole and the larger plug must not enter. Likewise, the larger ring gauge must go over the shaft and the smaller one must not go over. If this is the case with both shaft and hole, it is evident that the total variation in the fit is not more than .002 inch for the case considered, and may be considerably less.

Now, suppose that it has been decided that the shaft must fit the hole with a given minimum amount of clearance. In that case, the two internal limit gauges must be smaller than their corresponding internal gauges by an amount equal to the given minimum amount of clearance. Thus, if the clearance is to be at least .001 inch, and the shaft and hole may vary .001 inch from the true dimension, which is, say, 1 inch, then the internal limit gauge may be made .9995 and .9985 inch, and the external limit gauge 1.0005 and 1.0015 inches.

18. Distinguishing Marks for Limit Gauges. There are no special directions required for making cylindrical limit gauges. It is well, however, to stamp the size on all the gauges and the words "go in" on the smaller plug gauge and larger ring gauge; on the larger plug gauge and smaller ring gauge, the words "not go in" may be stamped. Another plan of distinguishing between the larger and the smaller gauges that will save the operator the time required to read the size and words, is to make the handles of the plug gauges and the outside of the ring gauges of different form. Thus, the handle of the larger plug gauge and the

outside of the smaller ring gauge may be fluted with semi-circular flutes, while the handle of the smaller plug gauge and the outside of the larger ring gauge may be nurled with a coarse nurling tool. If this is done, the operator that uses the limit gauges will quickly discover that nurling stands for "not go in" and fluting for "go in." While this may appear like a small matter on first thought, it should be remembered that careful attention to such small details will sensibly increase the output of a machine operator.

A handy method of constructing a cylindrical-plug limit gauge is shown in Fig. 5 (*a*). Here the plug gauge is made

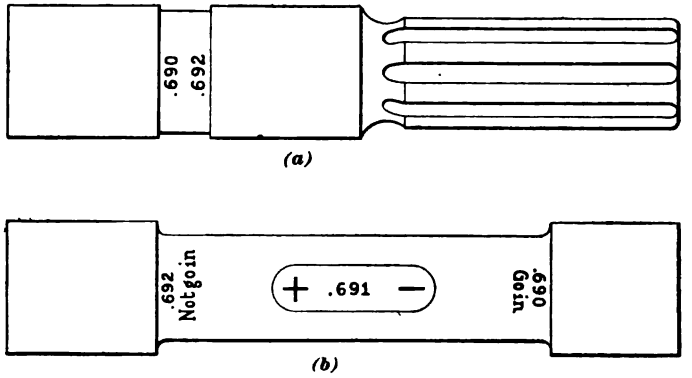


FIG. 5.

of two different diameters separated by a neck of ample size. The difference in the two diameters is equal to the allowable limit of variation. Evidently, if this gauge is used, the operator can gauge a hole faster than when two separate gauges are employed. Judgment will indicate when and where this style of plug gauge can be used. A somewhat different plug limit gauge is shown in Fig. 5 (*b*). Here the gauges are at the ends, and the handle is between them. The larger, or "not go in," gauge is made longer than the smaller gauge, so that one look will be sufficient to inform the operator which end is the larger. As it seems natural to assume that the longer end is the larger in diameter, it is recommended that it be made thus.

SNAP GAUGES.

19. Advantages of Snap Gauges. — A **snap gauge** has its own sphere of usefulness, being superior for some work to a ring gauge. In the first place, a snap gauge is adapted to measuring work having a cross-section other than round; for cylindrical work done between centers, it is not necessary to take the work out of the lathe to test it; it is also claimed that a deviation from the true size can be more readily detected by it than by a ring gauge. Furthermore, by applying it in several directions, the roundness of work can be tested. This cannot be done with a ring gauge. It is easy to conceive that an alleged cylindrical piece of work may apparently be a very good fit in a ring gauge, and be slightly oval at the same time. Unless the divergence from a circle is rather great, the ring gauge will not show it; the snap gauge will show a very minute deviation, however. It can also be used for measuring a neck between two collars.

20. Form of Snap Gauges.—Snap gauges may be designed in a great variety of forms, to suit different purposes and conditions. The most common form of an external gauge is that shown in Fig. 6. In order to pass over cylindrical work, the depth of the opening must be slightly more than the radius of the piece; that is, slightly over half the gauge size. When a snap gauge of this kind is intended for flat work, the depth of the opening is to be made to suit the work. In order that the size of the gauge may be retained, an inside end gauge may be made; if the size of the snap gauge must be very accurate, an inside gauge is absolutely required in order to produce the correct size of opening. When snap gauges take the place of plug and ring gauges, the plug gauge is replaced by the inside

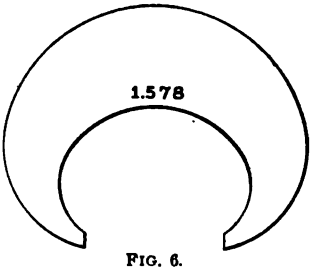


FIG. 6.

snap gauge shown in Fig. 7. This, in its simplest form, is a flat piece of tool steel with a handle formed on one end and circular measuring surfaces of the correct diameter at the

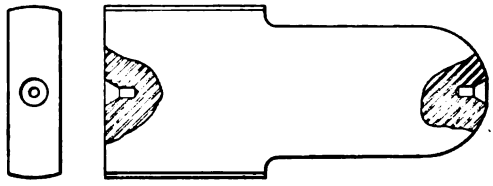


FIG. 7.

other end. When the inside snap gauge is intended solely for holes or slots of rectangular cross-section, the measuring surfaces are usually made to form parallel plane surfaces that are the correct distance apart.

21. Snap Limit Gauges.—For many classes of work, the snap gauge may advantageously be used as a limit gauge. It may then be formed with an opening at each end,

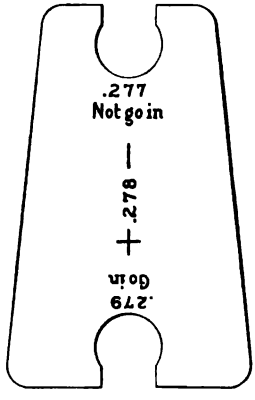


FIG. 8.

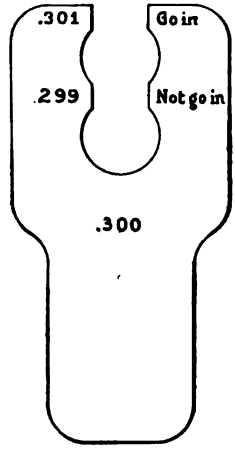


FIG. 9.

as shown in Fig. 8. It is a good idea to make the ends of the gauge of different shape, in order to make a distinction between the large and small opening ; thus, the gauge may

taper on the outside, being larger at the end that has the larger opening. A limit snap gauge may often be made advantageously of the form shown in Fig. 9. If thus made, the work can be gauged without reversing the gauge, thus effecting a saving of time and muscular effort on the part of the operator.

The degree of accuracy with which a snap gauge must represent its nominal size naturally determines the method by which it is to be made. Thus, if the gauge is accurate enough if within .01 inch of its nominal size, and if slight wear is unobjectionable, it would be a decided waste of time to finish the gauge dead true to size by grinding and lapping. If the limit of variation is not to exceed .001 inch, grinding will usually have to be resorted to, and if the wear is to be kept down to a minimum, lapping becomes essential after grinding.

22. Making Snap Gauges.—Except when the size of the outside gauge is so large that an inside micrometer can be applied, the inside gauge has to be made first; the outside snap gauge is then finished to fit the inside gauge. If the inside gauge simply serves the purpose of a reference gauge to preserve the gauge size, it may conveniently be a cylindrical bar having its end squared nicely and finished to the correct size. A good way of making such a bar is shown in Fig. 10. A piece of tool steel about $\frac{1}{2}$ inch longer than the inside gauge is to be, is turned between centers, and then necked down on both ends, as shown. The two disks thus formed are intended to be broken off finally, in order to get rid of the centers. After turning, harden at the ends or all over, according to size. Grind the outside straight and true and then break off the disks. After this is done, the ends are ground square and flat in a grinding machine, holding the gauge in a chuck and finishing to within a small amount of the finished size. The final bringing to size is to be done by lapping.



FIG. 10.

In order to insure parallelism of the two measuring surfaces, it is recommended that the device shown in Fig. 11 be used for lapping. This little device may be made of any suitable piece of scrap. As shown, it has a central hole bored to a good sliding fit for the gauge. A narrow ring of liberal outside diameter is faced off square with the hole; this may be done at the same chucking in which the hole is bored, or by mounting the device on a true-running arbor after boring the hole and then facing it while running the arbor between the centers. The inside gauge is inserted into the hole and pushed down level with the faced end; by moving the device to and fro on a small, planed, cast-iron plate charged with fine emery and oil, the ends of the gauge may be lapped true and square, and parallel to each other.

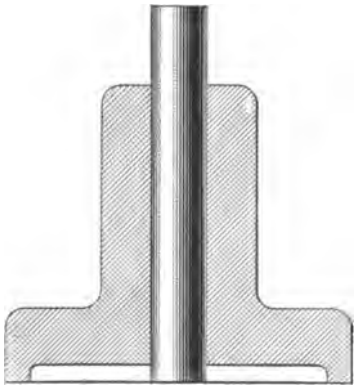


FIG. 11.

Frequently, it is most convenient to make the inside gauge from drill rod, which is true and straight enough not to require any finishing on the outside. If the gauge is hardened at the ends only, there will be little danger of springing it. A gauge made from drill rod is ground on the ends and then lapped in the manner just explained.

Flat gauges of the form shown in Fig. 7 are to be ground to size after hardening, leaving them about .0005 inch over size. They are then reduced to accurate size by careful oil-stoning with a very fine Arkansas stone.

Inside gauges that have their measuring surfaces parallel and forming plane surfaces are ground straight and parallel in a surface grinder. In order to last well, they should have their measuring surfaces finished by lapping. Evidently, lapping can only be done either by rubbing the measuring surfaces on a lap charged with the necessary abrading material, or by rubbing the lap over the surfaces. In either

case, there will be a tendency to lap the surfaces "crowning." To overcome this difficulty, hardened pieces of steel,

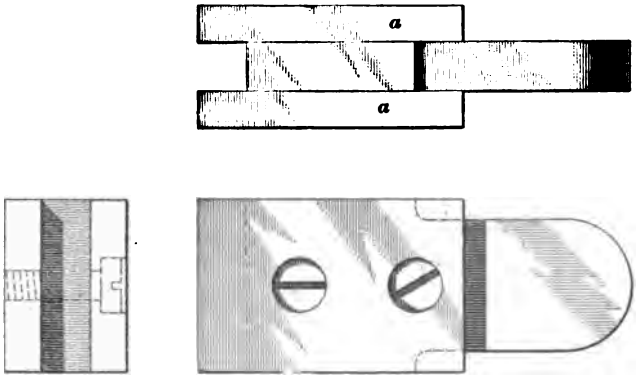


FIG. 12.

as *a*, *a*, in Fig. 12, may be temporarily fitted to the sides of the gauge and ground at the same time the gauge is ground. The lapping operation will then round the surfaces of these guard pieces, but leave the gauge surfaces flat. When the gauge is lapped to size, the guard pieces are removed and thrown away.

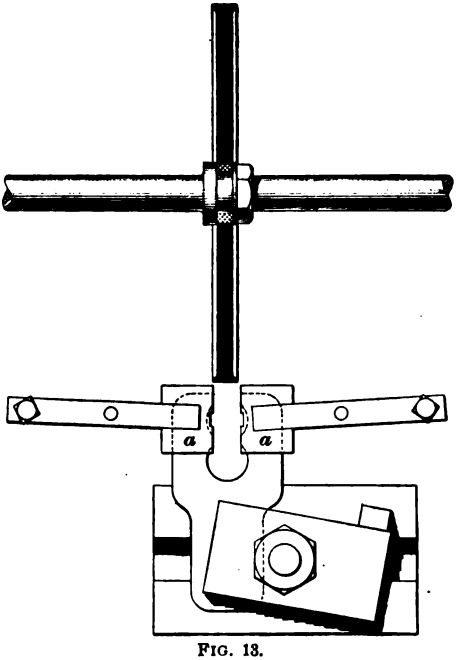


FIG. 13.

Outside snap gauges can be ground after hardening by using the method shown in Fig. 13. If no suitable grinding machine is available, any engine lathe can be used. Mount a thin and large emery wheel that has

been recessed, as shown, on an arbor between the lathe centers. Put a small pulley on the arbor and drive from any convenient overhead pulley. Clamp the gauge to the top of the slide rest; clamp guard pieces of hardened steel, as *a*, *a*, to each side of the gauge and on the top and bottom; then grind by feeding in by means of the cross-feed screw. Finish by lapping to size and then remove the guard pieces. With reasonable care, a very good job can thus be made.

ANGULAR GAUGES.

23. Names of Angular Gauges.—Gauges for angular measurements are made to represent either definite angles or tapers, which are the equivalent thereof. When they represent tapers, they are most commonly known as *taper gauges*, and their size is expressed by the taper in inches per foot they represent. Angular gauges have their sizes expressed in degrees and minutes, although, occasionally, they receive a special name. Thus, an angular gauge measuring a 90° angle is most commonly known as a *try square;* a gauge measuring an angle of 180° is familiarly called a *straightedge;* and a gauge that represents a 60° angle, from its most general application, is best known as a *thread gauge*.

24. Laying Out Angles.—Angular gauges may be made in different ways, according to the degree of accuracy required. If only a reasonable degree of accuracy is required, the given angle or taper may be laid off on a piece of sheet steel, which is then filed to the lines scribed thereon. If this method of construction is considered accurate enough, an angle may be laid off most conveniently by the aid of a table of natural sines and tangents. Scribe a straight line, as *a* in Fig. 14, on the surface of the piece of steel. Make two very fine center-punch marks, as *b* and *c*, on this line and as far apart as circumstances permit. At *c* erect a perpendicular, as *c d*. Measure the distance *b c* as accurately as possible with a steel scale, preferably with a decimally divided scale. From a table of natural tangents, take the

tangent of the required angle and multiply the distance *b c* by this tangent. Then, on *c d* lay off as accurately as possible the product of *b c* and the tangent, marking it by a fine

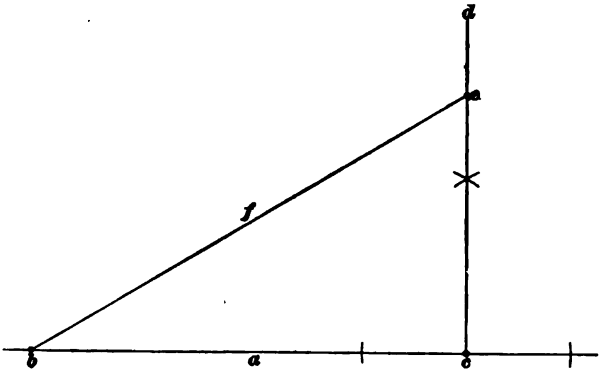


FIG. 14.

center-punch mark, as *e*, made on the line *c d*. Scribe a line through *b* and *e*; the angle *e b c* included between the lines *a* and *f* is the required angle.

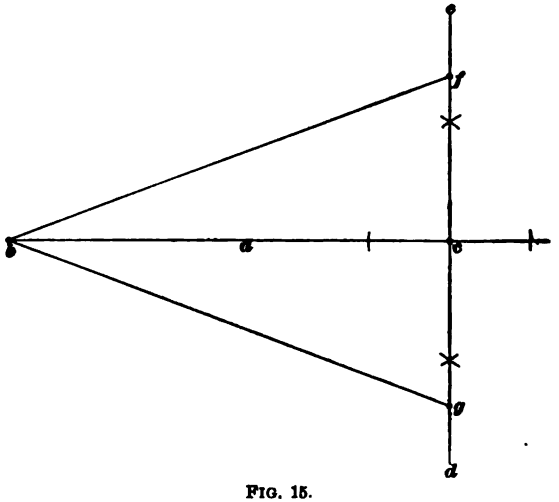


FIG. 15.

25. When the required angle is greater than 45°, it is more convenient to use the method shown in Fig. 15. Scribe

the line *a* and on it lay off *b c* as long as convenient. At *c* erect the perpendicular line *d e*. From a table of natural tangents, take the tangent corresponding to one-half the required angle; multiply the distance *b c* by this tangent and lay off the distance thus found on both sides of *c*, marking it at *f* and *g*. Join *f* and *g* to *b* by straight lines. The angle *f b g* is then the required angle.

26. When the required angle is greater than 90°, instead of laying off that angle, its supplement is laid off. Subtract the required angle from 180° and lay off the angle thus found. Thus, if the required angle is 110°, lay off the angle *b a c*, Fig. 16, equal to 180° − 110° = 70° by the method given in Art. **25.** The angle *d a b* is then 110°.

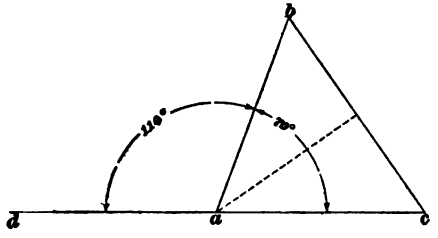


FIG. 16.

The correctness with which an angle can thus be produced naturally depends on the skill of the workman in working to the scribed lines and on the accuracy with which they have been located. As a general rule, it may be stated that a much greater degree of accuracy can be obtained by this method than is possible by laying off angles with the ordinary bevel protractor made for machine-shop work. All other factors remaining as before, the accuracy attainable will be greater as the base line, as *b c*, Figs. 14 and 15, or *a c*, Fig. 16, is made longer.

TAPER GAUGES.

27. Different Definitions of Taper.— When an angular gauge is ordered to represent a certain taper per foot, the toolmaker should find out by inquiry, first of all, what the person ordering the gauge understands by the term "taper." Unfortunately, the term has no definite

meaning, being used in different senses in different localities. Referring to Fig. 17 (*a*), the taper is defined by some as the difference in diameters ($d-d'$) per foot of length, the taper in all cases being expressed in inches and fractional parts of an inch. The measurements for diameter are made on lines perpendicular to the axis, which is also the line bisecting the angle made by the sides *a b* and *e f* of the tapering piece. In Fig. 17 (*b*) the difference in the radii ($r-r'$) per foot of length is considered as the taper. In this case,

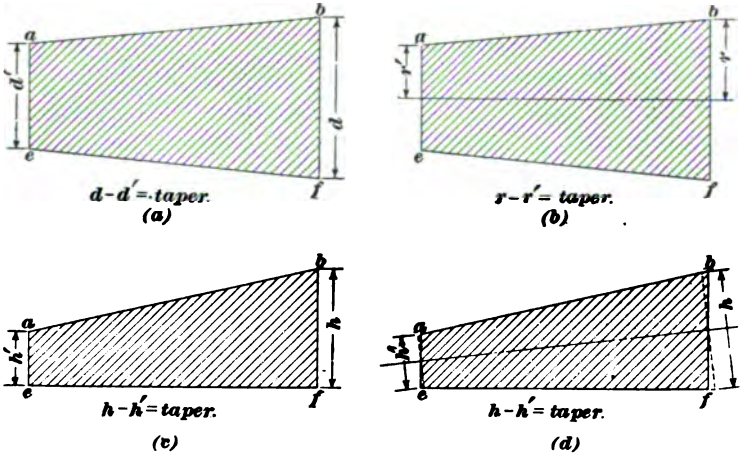


FIG. 17.

the measurements for the taper are made on lines perpendicular to the axis, or line bisecting the angle included between *a b* and *e f*, but only to one side of the axis. Evidently, if the taper is expressed in accordance with Fig. 17 (*b*), it will be only one-half that of Fig. 17 (*a*), but yet the angle included between *a b* and *e f* will be the same in either case.

When the taper of flat work, as keys or wedges, is measured, probably the most common way is to take one side, as *e f*, Fig. 17 (*c*), as a base line and measure the taper by the difference ($h-h'$) in height of perpendiculars, as *e a* and *f b*, erected at the ends of the base line. Many persons will measure the taper of flat work in the manner shown in

Fig. 17 (*d*). Here the difference in height is measured to both sides of a line bisecting the angle included between the sides *a b* and *e f* and on lines perpendicular to the bisecting line. This method is the same as that shown in Fig. 17 (*a*). Now, on first thought it would seem, when comparing two pieces of the same nominal taper, of which one has been measured according to Fig. 17 (*c*) and the other according to Fig. 17 (*d*), as if there were no difference in the angles included between *a b* and *e f*. There is a decided difference, however, as can be seen by referring to Fig. 18. In this

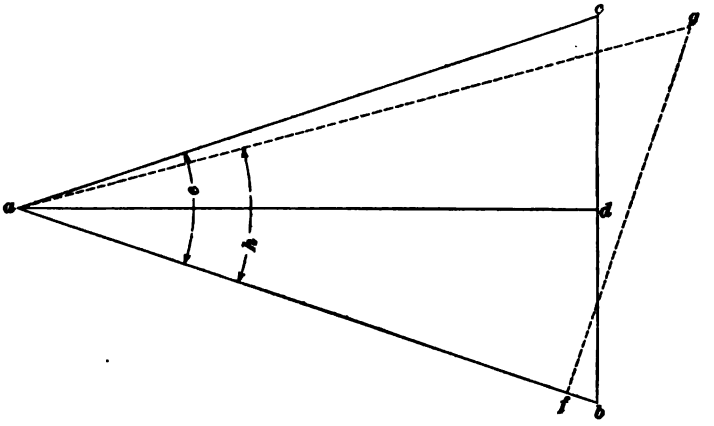


FIG. 18.

figure, the triangle *a f g* represents a taper of 8 inches per foot measured in accordance with Fig. 17 (*c*); the triangle *a b c* also represents a taper of 8 inches per foot, but measured in accordance with Fig. 17 (*d*). An inspection shows that there is a decided difference in the angles *e* and *h*.

28. Laying Out a Taper Gauge. — If a **taper gauge** is to be laid out on sheet steel, the method of laying it out naturally depends on the method by which the taper is measured. Suppose a taper gauge is to be made for a flat wedge that is three inches long on one side and 1 inch high at the thick end. The taper is to be 1 inch per foot,

and the person ordering the gauge wants the taper to be measured by taking the measurements perpendicular to one side, that is, as shown in Fig. 17 (*c*). Then, before the lines can be scribed on a sheet-steel gauge, the height at the thin end of the wedge must be calculated. If the taper is measured as shown in Fig. 17 (*a*), (*c*), or (*d*), the difference in height, or in diameter in case of round work, may be found by the followlng rule :

Rule.—*Divide the given length by 12 and multiply by the taper.*

When applying this rule to a taper measured as in Fig. 17 (*d*), it is to be observed that it gives the difference in height of lines the given distance apart and perpendicular to the line bisecting the angle, on which line the given distance is measured. If the taper has been measured as shown in Fig. 17 (*b*), the result given by the rule must be doubled to obtain the difference in diameters.

Applying the rule given, we get, for the case under consideration, $\frac{3 \times 1}{12} = \frac{1}{4}$ inch as the difference between the large and small ends. Then, the small end is evidently $1 - \frac{1}{4} = \frac{3}{4}$ inch high. The laying out of the gauge is now a simple matter. Draw a straight line 3 inches long ; erect perpendiculars at the ends $\frac{3}{4}$ inch and 1 inch high, and join the ends of the perpendiculars by a straight line. Then cut out the metal and file to the lines.

When the taper has been measured in accordance with Fig. 17 (*a*) or (*d*), scribe a straight line of the required length and at its ends erect perpendiculars. Lay off half the heights (or diameters) on each side of the line first scribed and join the ends of the perpendiculars by straight lines.

When making a sheet-metal taper gauge or angular gauge, it is not advisable to cut out the metal with a chisel, since this may spring it considerably out of true. It is better to saw out the metal with a hack saw, or drill a row of holes close together and then cut through the metal remaining between the holes with a saw or file.

29. Originating Tapers and Angles. — The most accurate way of originating a taper or an angle (except a 60°, 90°, and 180° angle) is shown in Fig. 19. The same

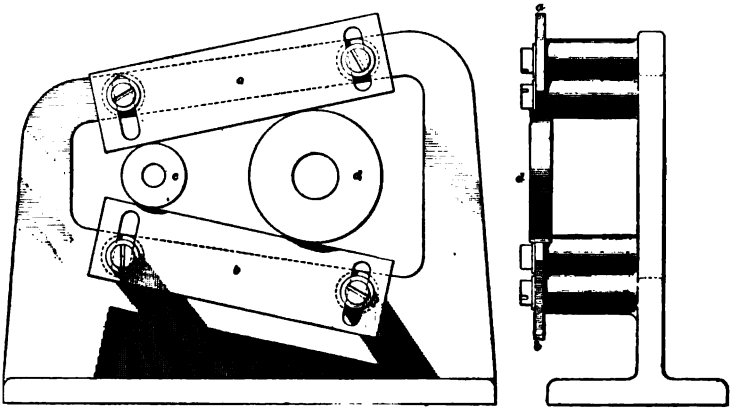


FIG. 19.

principle that is involved in originating a taper or angle allows the same method to be used to measure accurately a taper or angle whose exact measure is not known.

In Fig. 19, *a* and *b* are two straightedges that are ground and lapped as nearly true as possible. They are so mounted in a suitable frame that they can readily be shifted and then locked rigidly. Steel disks *c* and *d* ground and lapped truly cylindrical and of any convenient diameter are placed between the straightedges and in contact with them. Then, the diameters of the disks and their center-to-center distance, all of which dimensions can be accurately measured, definitely determine the taper included between the straightedges, or the angle, and these data can then be calculated by the following rules:

30. If the taper is measured in accordance with the method shown in Fig. 17 (*a*) and (*d*), the taper included between the straightedges is calculated as follows:

Rule.—*Divide the difference in the diameters of the disks by twice their distance from center to center. From a table*

of natural sines, take the angle corresponding to the quotient. Then, in a table of natural tangents, find the tangent corresponding to this angle. Multiply the tangent by 24.

If the taper is measured in accordance with Fig. 17 (*b*), divide by 2 the result obtained by the rule just given.

EXAMPLE.—The disks being 2 inches and 4 inches in diameter, and their center-to-center distance being 4.5 inches, (*a*) what is the taper in inches per foot if measured in accordance with Fig. 17 (*a*) or (*d*)? (*b*) What is the taper if measured as in Fig. 17 (*b*)?

SOLUTION.—(*a*) Applying the rule given, we get $\frac{4-2}{2\times 4.5} = .22222$ as the sine. The nearest angle is 12° 50′. The tangent corresponding to this angle is .22781. Then, the taper is $.22781 \times 24 = 5.4674$ in. per ft. Ans.

(*b*) Dividing answer in (*a*) by 2, we get $5.4674 \div 2 = 2.7337$ in. per ft. Ans.

31. If the taper is measured according to Fig. 17 (*c*), use the following rule:

Rule.—*Divide the difference in the diameters of the disks by twice their distance from center to center. Find the corresponding angle in a table of sines; double the angle thus found and find its tangent. Multiply the tangent by 12.*

EXAMPLE.—Taking the same values as in the previous example, what will be the taper per foot if measured in accordance with Fig. 17 (*c*)?

SOLUTION.—Applying the rule just given, we get $\frac{4-2}{2\times 4.5} = .22222$ as the sine. The nearest angle is 12° 50′. Doubling this angle, we get 25° 40′. The corresponding tangent is .48055. Then, the taper is $.48055 \times 12 = 5.7666$ in. per ft. Ans.

32. When the taper in inches per foot is given, to find the diameters of the disks and their center-to-center distance:

Rule.—*Assume the diameters of the disks as dictated by judgment. Divide the taper by 24, if the taper is measured in accordance with Fig. 17 (a) or (d). If measured in accordance with Fig. 17 (b), divide the taper by 12. From a table of natural tangents, find the angle corresponding to the quotient. Then, from a table of natural sines, take*

the sine corresponding to the angle. Finally, divide the difference in the diameters of the disks by twice the sine.

EXAMPLE.—If a taper of 2 inches per foot is to be originated, what must be the center-to-center distance of the disks, assuming them to be 2 inches and 3.5 inches in diameter, (*a*) if the taper is measured according to Fig. 17 (*a*) and (*d*)? (*b*) if the taper is measured according to Fig. 17 (*b*)?

SOLUTION.—(*a*) By the rule just given, $2 \div 24 = .08333$. The nearest angle corresponding to this tangent is 4° 46′. The sine of this angle is .0831. Then, $\frac{3.5 - 2}{.0831 \times 2} = 9.0253$ in. Ans.

(*b*) $2 \div 12 = .16666$. The nearest angle corresponding to this tangent is 9° 28′. The sine of this angle is .16447. Then, $\frac{3.5 - 2}{.16447 \times 2} = 4.560$ in. Ans.

33. When the taper is given in accordance with Fig. 17 (*c*), assume the diameters of the disks as dictated by judgment. Then, to find their center-to-center distance:

Rule.—*Divide the taper by 12. From a table of natural tangents, find the corresponding angle. Find the sine of half the angle thus found, and divide the difference in the diameters of the disks by double the sine.*

EXAMPLE.—If the disks are 2 inches and 3.5 inches in diameter, what must be their center-to-center distance to produce a taper of 2 inches per foot measured in accordance with Fig. 17 (*c*)?

SOLUTION.—Applying the rule just given, $2 \div 12 = .16666$. The nearest angle corresponding to this tangent is 9° 28′. Half of this angle is 4° 44′. The sine corresponding is .08252. Then, $\frac{3.5 - 2}{.08252 \times 2} = 9.0887$ in. Ans.

34. It occasionally happens that it is desired to find the angle included between the lines *a b* and *e f*, Fig. 17, when the taper is given. Then, if the taper is measured as in Fig. 17 (*a*) and (*d*):

Rule.—*Divide the taper by 24. Look up this value in a table of natural tangents and double the corresponding angle.*

EXAMPLE.—What angle corresponds to a taper of 3 inches per foot, if the taper is measured as in Fig. 17 (*a*) and (*d*)?

SOLUTION.—By the rule just given, 3 + 24 = .125. The nearest angle is 7° 8′ and twice this angle is 14° 16′. Ans.

35. If the taper is measured as in Fig. 17 (*b*):

Rule.—*Divide the taper by 12. Find the corresponding angle in a table of natural tangents and double it.*

EXAMPLE.—A taper of 3 inches per foot is given in accordance with Fig. 17 (*b*). What is the angle?

SOLUTION.— 3 + 12 = .25. The nearest angle is 14° 2′. Then, the required angle is 14° 2′ × 2 = 28° 4′. Ans.

36. If the measurement for taper is made according to Fig. 17 (*c*):

Rule.—*Divide the taper by 12. From a table of natural tangents, find the angle corresponding to the quotient.*

EXAMPLE.—What angle corresponds to a taper of 3 inches per foot measured as in Fig. 17 (*c*)?

SOLUTION.— 3 + 12 = .25. The nearest angle = 14° 2′. Ans.

37. When the straightedges of Fig. 19 are to be set to a given angle by means of the disks, their center-to-center distance may be found as follows:

Rule.—*Take the sine of half the angle from a table of natural sines. Divide the difference in the diameters of the disks by double the sine.*

EXAMPLE.—If an angle of 20° is to be originated, and the disks are 2 inches and 4 inches in diameter, what must be their center-to-center distance?

SOLUTION.— 20° + 2 = 10°. The sine of 10° = .17365. Then, $\frac{4-2}{.17365 \times 2} = 5.7587$ in. Ans.

38. In case it is desired to measure the angle included between the straightedges:

Rule.—*Divide the difference in the diameters of the disks by twice their center-to-center distance. From a table of natural sines, take the angle corresponding to the quotient and double it.*

EXAMPLE.—The disks being 2 inches and 5 inches in diameter, and 5 inches from center to center, what is the angle included between the straightedges?

SOLUTION.— $\frac{5-2}{2\times 5} = .3$. The nearest angle is 17° 27′. Then, 17° 27′ × 2 = 34° 54′. Ans.

39. If the center-to-center distance calculated by any of the rules previously given is less than half the sum of the diameters of the disk, either one of the disks must be made smaller or the other one larger, and the calculation repeated until the distance becomes larger than half the sum of the diameters.

The center-to-center distance can be measured in two ways: Measure the distance between the disks and add half the sum of the diameters; or measure the distance over the outside of the disks and subtract half the sum of the diameters.

In order to originate an accurate taper gauge for flat work, the device shown in Fig. 19 is set to the given taper. An inside gauge is then fitted to it, continuing the fitting until no daylight can be seen, when the gauge is placed between the straightedges. The outside gauge is then carefully fitted to the inside gauge just made; it thus becomes a duplicate of the taper (or angle) included between the straightedges. If necessary, either one of the pair of gauges is kept as a reference gauge to show wear of the other.

Taper gauges for round work (conical work) are made both as inside, or plug, and as outside gauges. The device is first set to the angle (or taper) required; the plug gauge is then ground until no daylight can be seen, when it is placed between the straightedges. The outside, or ring, gauge is next ground until it exactly fits the plug gauge, using the finest grade of Prussian blue as a marker to show the fit.

40. Originating a 60° Angle.—A 60° angle can be originated most readily by the method first used by Pratt & Whitney for originating a standard with which thread

gauges could be compared. The principle made use of is that in an equilateral triangle each interior angle is equal to 60°. Then, if three bars are made, as *a*, *b*, and *c*, Fig. 20,

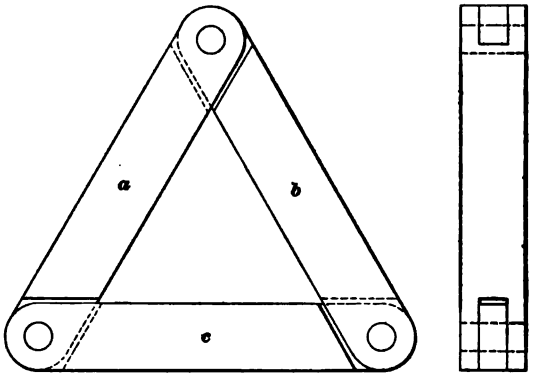


FIG. 20.

each of them exactly equal to the other, and with the holes the same distance apart and in the same relative positions in regard to the sides, the center lines of these bars when connected by pins passing through the holes will form an equilateral triangle; and, as the inside and outside surfaces of the bars are parallel to the center line, all angles included between the inside or outside of the bars will be 60° angles.

TRY SQUARES.

41. Making a Try Square.—A 90° angle may be originated in several ways. The first method here given will produce two **try squares,** both of which, if skilfully made, will be about as correct as it is possible to produce them. There is one appliance necessary, however, on the truth of which the correctness of the try squares will depend. This appliance may be either a straightedge or a surface plate; either one of them may be used, but it must be as true as skill and ingenuity can make it. When making try squares, it is easiest, as a general rule, to do all truing on

the blade, since the amount of metal to be removed is usually quite small.

To make the try squares, finish the stocks by grinding their top and bottom surfaces parallel and as nearly plane as possible. A surface-grinding machine is invaluable for this work. If it must be done by hand, great care is required to make as good a job of it as can be done by the surface-grinding machine. The two stocks having been finished,

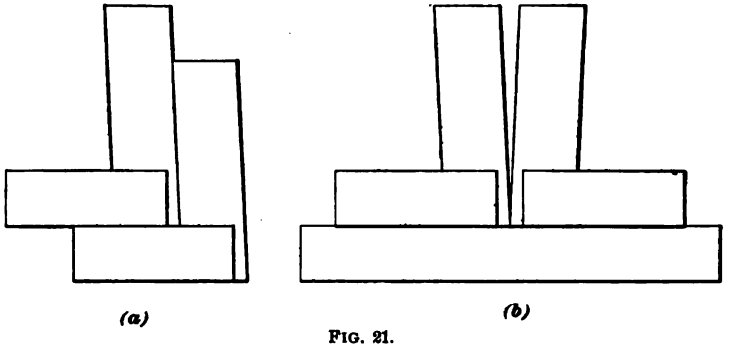


FIG. 21.

insert and fasten the blades, which have been previously ground true and parallel. Select the square that seems to be the most accurate, using judgment in the selection. Fit the other square to it until they fit either way, when stock is placed against stock and blade against blade, as shown in Fig. 21 (*a*).

The two squares are now duplicates of each other, but it is not known as yet whether the angle between stock and blade is correct, or if not, which way the squares are out. To test this, place both squares blade to blade on a surface plate or straightedge, as shown in Fig. 21 (*b*), and with the stocks resting on the surface plate or straightedge, observe if the blades are in contact with each other throughout their length. If they touch so that no daylight can be seen between them, both squares are correct. Suppose, however, that there is an opening at the top, as shown in Fig. 21 (*b*). Then, this shows that the angle between stock and blade is smaller than 90°; conversely, if the opening is at the bottom,

the angle is larger than 90°. Next, take one of the squares and shift its blade one-half the amount indicated. If the shifting must be done by grinding the blade, grind off the probable amount on one side and then make the other side absolutely parallel to it. Now, fit the second square to the first square just corrected; place them blade to blade again on the surface plate or straightedge, and repeat the cycle of operations until the squares will fit when placed stock to stock and blade to blade. Both squares will then be correct.

42. Testing Try Squares.—If a try square is to be tested for correctness, the most obvious way is to compare it with a test, or reference, try square. If there is none at hand and circumstances permit, an excellent substitute for a test square may be made as shown in Fig. 22. Take a piece of good machinery steel or well-annealed tool steel having a length not less than the length of the blade of the try square, and a diameter of not more than the inside length of the stock. Recess one end about $\frac{1}{16}$ inch deep, making the diameter of the recess about $\frac{1}{8}$ inch less than the outside diameter. Turn the outside true and straight; slightly bevel the edge at the recessed end and then finish by grinding and lapping between dead centers, and finally, without previous removal from the grinding machine, accurately face the annular ring at the cupped end. Obviously, if the cylinder is finished true and straight, the angle between the plane of the ring and the cylindrical surface is a right angle.

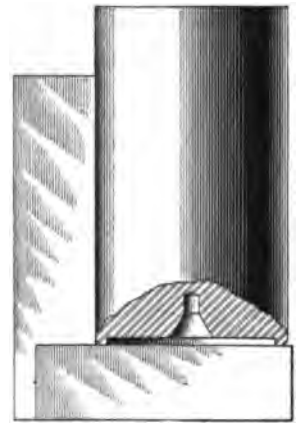


FIG. 22.

Since there should not be any difficulty in lapping the device straight within a variation of .00002 inch, and since the ring can be ground to be in a plane perpendicular to the axis within an insensible amount of variation, it is

believed that this is the most accurate method of originating a 90° angle that has been devised. This device may be used for testing the truth of the inside and outside angles of a try square. To test the inside angle, the try square is applied directly to the device, as shown in Fig. 22. To test the outside angle, the device and try square are both placed on a surface plate and brought in contact with each other. Practical considerations will fix a limit within which this device can be used. These considerations are the weight allowable and the facilities for grinding and lapping; from these, the toolmaker can readily determine the limits within which the method just given is applicable.

A simple method of testing try squares intended for comparatively rough work is shown in Fig. 23. One edge of a

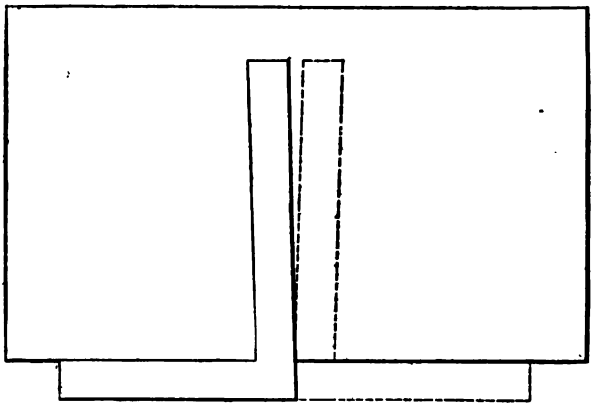


FIG. 23.

wooden or metal plate that forms a fair approximation to a plane surface is trued up to a straightedge. The stock of the square is then placed against this edge and a faint line is scribed along the blade. The square is now reversed, as shown by the dotted lines; if the blade coincides with the scribed line, the square is true. If the blade is farther away from the line at the top than it is near the stock, it shows that the angle is less than 90°; conversely, if it is farther away near the stock than at the end of the blade, the

angle is larger than 90°. This method shows double the error.

43. Making a Test Block for a Square.—A refined method of making a test block for testing try squares was made public in 1896 by Mr. G. A. Bates, an expert toolmaker of Brooklyn, New York. The construction of the test block is shown in Fig. 24. It consists of a rectangular

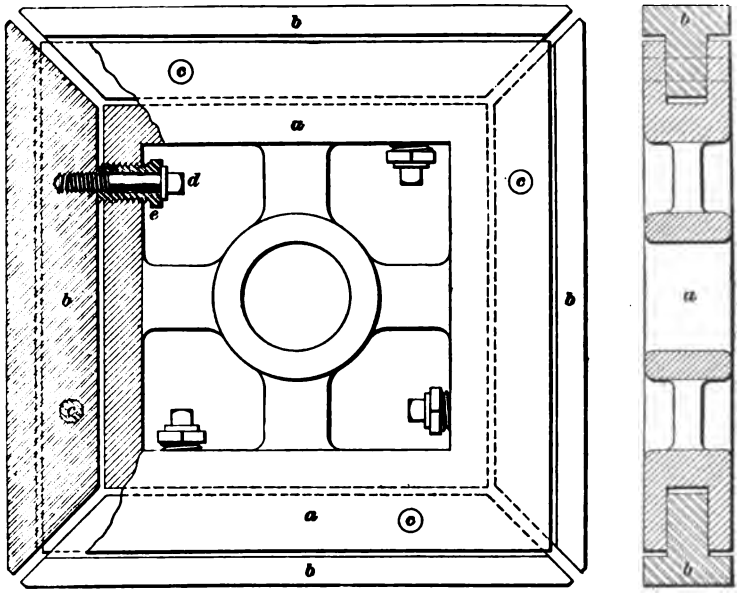


FIG. 24.

cast-iron frame *a*, which has a groove of rectangular cross-section all around its circumference. The sides of the groove are finished straight and parallel by planing or milling. Four separate blades, as *b*, *b*, are closely fitted to the groove in the frame; they are connected to the frame by well-fitted fulcrum pins *c*, *c* located near one end of the blades. The end of the blades opposite the pins is connected to the frame by small bolts, as *d*, which fit tapped holes in the blades and pass through a clearance hole in setscrews, as *e*; these setscrews are fitted to holes tapped in the frame.

Evidently, by moving the setscrews and setting up the locking bolts, each blade can be rotated slightly around its fulcrum and then locked in position. While the blades are shown as having a T shape, they may be made rectangular as well, or, if considered desirable, the edges projecting from the frame may be thinned down by beveling. The measuring surfaces of the blades are filed and scraped so as to make true plane surfaces, scraping them either to a true surface plate or to a true straightedge. It should be remembered that the value of the test block depends, to a large extent, on the straightness of the measuring edges; hence, these must be made as perfect as skill and ingenuity can make them. The setscrews *e* and locking bolts *d* should have a rather fine pitch of thread, say 40 threads per inch, or even finer, as a sensitive adjustment can then be readily obtained. The screws *e* must be a good snug fit, since any looseness will destroy the value of the testing block.

44. In order to set the test block so that any two adjacent blades are at a right angle to each other, a temporary try square is made out of sheet iron or sheet steel. A very convenient form of such a try square is shown in Fig. 25. Instead of finishing the inside of the blades throughout their length, they are cut away in order to leave the small projections shown. When any change is required, it is easier to dress down the projections than to refinish the blade throughout its length

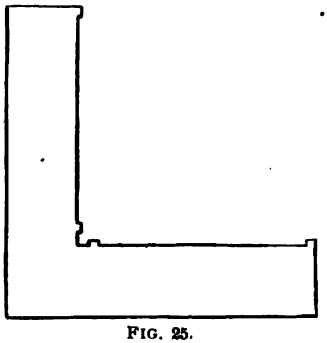


FIG. 25.

The try square having been finished until it is believed to be fairly accurate, it is applied to two adjacent blades of the test block. One of these blades is then adjusted until both blades fit the temporary try square. Suppose the try square has been used on the top and right-hand blade of the test block and that the top blade has been adjusted. Then, it is

next applied to the top and left-hand blade; the latter is now adjusted to fit the try square. The bottom blade is finally adjusted from the left-hand blade and to the try square; on applying the try square to the bottom and right-hand blade, any error of the try square will be shown multiplied four times. The try square is now corrected and the blades of the test block readjusted. These operations are repeated until the try square fits exactly all around the test block; when this is the case, any two adjacent blades of the test block are at a right angle to each other, and the try square is also truly square.

STRAIGHTEDGES.

45. Originating a Straightedge. — A correct straightedge can be produced either by fitting it to an

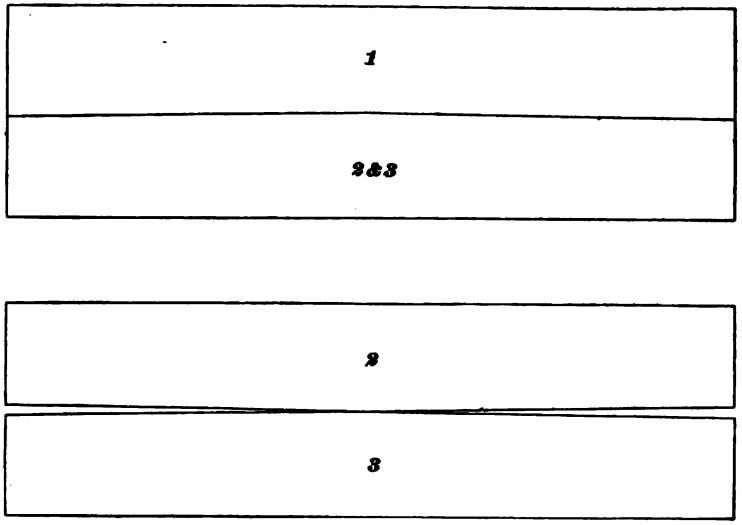


FIG. 26.

absolutely correct surface plate, or it can be originated in accordance with the following axiom: *Three straightedges cannot fit one another unless all three are straight.* The

facilities at command of the toolmaker will determine which method is to be used.

Three straightedges having been finished all over, select one of these as a trial straightedge; perferably select the one that is believed to be nearest correct. Mark this *1*, and mark the two others *2* and *3*, respectively. Carefully fit straightedges *2* and *3* to *1*, as shown in Fig. 26, until no daylight can be seen between *1* and *2* and *1* and *3* when holding them up against a strong light. This done, place *2* and *3* together, as shown in the illustration. Any deviation from a straight line will now show double. Take one of these two equal straightedges, say *2*, and reduce its error. Use this as a trial straightedge and fit *1* and *3* to it. Place *1* and *3* together, observe the error, and reduce it on number *3*. Use *3* as a trial straightedge and fit *1* and *2* to it. Place *1* and *2* together, reduce the error of *1* and use it as a trial straightedge once more, fitting *2* and *3* to it. Repeat these operations until all three straightedges fit one another; all three will then be straight.

It is not possible to use fewer than three straightedges, since two straightedges can be perfectly fitted to each other, and be a perfect fit on each other in any position in which they are placed, without being anywhere near true.

46. Forms of Straightedges.—Straightedges are made in various forms. Most generally they are made rectangular in cross-section, and of uniform width throughout their length. They must then be made wide and thick enough to give stiffness sufficient to prevent any sensible deflection with reasonable care in their use. If their width is made equal to .12 times the length increased by .6 inch, and their thickness equal to .005 times the length increased by .05 inch, a satisfactory degree of stiffness can usually be obtained, provided the length of the straightedge does not exceed 40 inches. Since toolmakers are by no means agreed upon what deflection is permissible, the proportions here given are to be considered as those that we think will give satisfactory results.

Straightedges become more sensitive, that is, they will more readily show a minute deviation, as their measuring edge is made narrower. They are most sensitive when made so that they touch the work merely along a line; i. e., when they are in line contact with it instead of in surface contact. Then, carrying out this idea, a straightedge may be given sufficient thickness and width in order to give stiffness, and it may be beveled at its measuring edge in order to give sensitiveness. Beveled straightedges are usually beveled sufficient to leave the measuring edge $\frac{1}{16}$ inch wide. When beveled off more than that, the cross-section bears a close resemblance to that of a knife blade, and the straightedge is then called a **knife-edge straightedge.**

A very satisfactory cross-section of a knife-edge straightedge is that adopted by Pratt & Whitney and shown in Fig. 27 (*a*). This form combines stiffness, lightness, and convenience of handling. The more common form is shown in Fig. 27 (*b*); it is simply beveled on both sides to give a narrow edge. In both forms of knife-edge straightedges, the actual testing edge *a* has a semicircular cross-section; in other words, the testing edge, instead of forming a plane surface, forms part of a cylindrical surface. When thus made, they can be held at a slight angle to the work, without in any way interfering with the correctness of the measurement. Hence, they are more easily used than straightedges in which the testing edge forms a plane surface; these must be held so that the testing surface is in contact all over with the surface to be tested, for if canted over so that one edge of the testing surface is in contact with the work, a wrong indication will be given if that edge should be out of true. As a general rule, in making straightedges with a plane-surface testing edge, little attention is paid to making the bounding edges of the testing

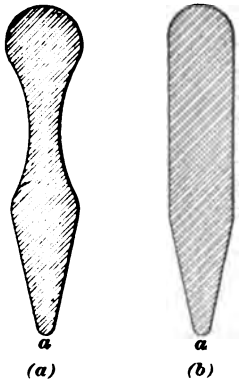


FIG. 27.

surface absolutely straight; this would add considerably to the cost without gaining any particular advantage. Besides, the sharp edges would rapidly wear out of true.

Knife-edge straightedges cannot be very readily originated by making three fit one another. The reason is that it is practically impossible to hold two of them together so as to be in contact all along. On account of this difficulty, knife-edge straightedges are usually fitted to a straightedge having a plane-surface testing edge, or to an accurate surface plate.

47. Hardening Straightedges.—Straightedges intended for work in the shop are usually hardened on the testing edge, and occasionally all over. The object of hardening is to reduce the liability of wear. Since the hardening process sets up severe internal stresses, which are gradually released by the aging of the steel, hardened straightedges will occasionally become crooked and require refitting. If the edge alone is hardened and the back is left soft, this change of shape will, as a general rule, be small enough to be negligible. Straightedges intended for reference only, i. e., for testing working straightedges, may be left soft; large straightedges must usually be left soft on account of the difficulty of hardening.

To harden a straightedge on the edge only, place it between iron bars clamped to it, leaving the edge exposed. Heat evenly all over and then quench. The iron bars prevent the water from coming in contact with the back and sides, which are consequently left soft.

48. Finishing the Testing Edge of a Straightedge.—To make a straightedge with a plane-surface testing edge, it should be ground as nearly straight as possible on a surface grinder, if hardened, and then finished by stoning and lapping. If left soft, it is finished by filing, scraping, and lapping. The straightedge having been finished very nearly true by filing with a dead smooth file, scraping is begun. A neat device for scraping, and one that

has proved very useful in this connection, is shown in Fig. 28. For want of a better name, and from its resemblance to the carpenter's plane, it may be called a **scraping plane.** As shown in the figure, it consists of a body, one side of which, as *b*, is finished by planing to suit the shape of the straightedge that it is intended for. The scraping tool is set so that its cutting edge is at an angle of about 60° with the line of motion of the plane; it will then take a shaving cut. The edge of the scraping tool slightly projects beyond the surface *a*, say about .0005 inch. It is stoned to a very keen edge, as nearly straight as possible; if made with a triangular cross-section of cutting edge, as shown, it will

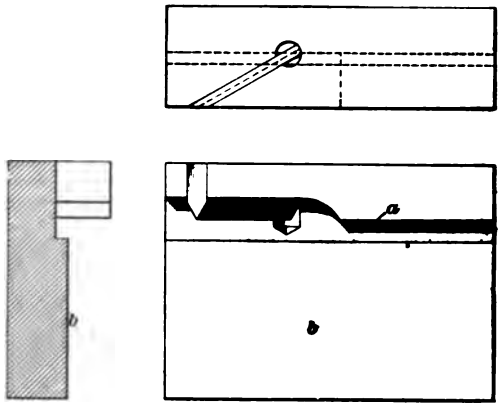


FIG. 28.

cut both ways, and make a very good job if supplied with plenty of lard oil and kept sharp. Suppose now that the plane is held with its surface *b* against the side of the straightedge, and, with the scraper resting on the testing edge, is moved back and forth. Then, it follows that, the scraper being prevented from canting over to one side or the other, the angle between the side of the straightedge and its measuring edge will be constant throughout the length.

In the illustration, the scraping tool is shown as being held in place by friction; if well fitted to the sides of the slot, this will be sufficient. If considered necessary, it may

be held in place by a key, or by screws; adjusting screws for setting it out may also be provided.

For the final finishing by lapping, a small L-shaped piece of cast iron may be provided. If the lapping is then done with one leg of the lap resting against the side of the straightedge, the lap cannot be canted to one side or the other, and, consequently, a good job can be done more rapidly than could be done otherwise.

Knife-edge straightedges, while the most sensitive straightedges that have been devised, are, at the same time, the most difficult ones to make. After grinding them as nearly straight and true as circumstances permit, they must be finished by oilstoning with a very fine Arkansas oilstone, frequently comparing them with a plane-surface straightedge. No special directions that could be given will make their production an easy matter; it is a matter of patiently stoning down the high spots until the knife edge fits the reference straightedge all along at any angle within range at which it may be held.

Very large straightedges, say, above 40 inches long, are rarely made as knife-edge straightedges; the usual plan is to make them in the form of a narrow surface plate and of cast iron. They may have a T shape, with a rib of ample depth and thickness to prevent deflection. Straightedges of this form are originated in the same manner as surface plates; one being kept as a reference straightedge, others may be made from it by comparison.

SPECIAL GAUGES.

49. Where a large number of pieces are to be made interchangeable, this quality can only be preserved by **limit gauges** so constructed as to caliper the piece in all essential directions. In some cases, one set of limit gauges will be sufficient; in others again, two or more sets may be required owing to the difficulty, if not impossibility, of gauging the work all over in one operation. Owing to the

infinite number of shapes possible, no definite rules can be given as to the construction of special gauges; each case must be treated on its own merits, and the toolmaker must exercise his ingenuity as to the best way of designing and constructing the gauges. The only general directions that can be given are to make the gauges as simple, durable, and capable of exact duplication as circumstances will permit. Furthermore, always provide means of getting the work out of the gauge, or the gauge away from the work without ruining the gauge, in case the work should stick.

A few special cases of gauge making are given below; the gauges shown and the remarks made in regard to them are intended only as suggestions of how a gauge may be made for the pieces of work shown. It is not to be inferred that the way the gauges are made is, in each instance, the best method of construction possible and the only one applicable. Circumstances alter cases; while a gauge designed as shown may be eminently suitable for one set of conditions, it may be either too refined or not refined enough for other conditions and requirements.

50. In Fig. 29 (*a*) is shown a rather simple piece of work, which is finished on the edges in a profiling machine,

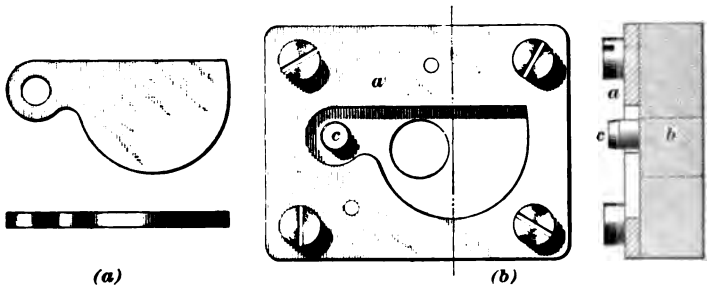


FIG. 29.

and has a hole through one end. The sides are to be parallel and of a given thickness. It is required to gauge the shape in relation to the hole; it is also essential that the hole and the thickness be correct. To gauge the hole, a cylindrical limit gauge may be employed; for the thickness, a

limit snap gauge is best adapted ; for gauging the shape, a gauge may be made as shown in Fig. 29 (*b*). The gauge consists essentially of a flat plate *a* pierced by a hole of the same shape and size as the work. This plate is mounted on a block *b*, which carries the pin *c*, and the latter serves to locate the work properly in the gauge. The pin is made the minimum size allowable for the hole in the work. Then, if the work is placed over the pin and if it drops into the hole pierced through *a*, it is known that the shape of the piece is not over the size.

The degree of accuracy with which the work fits into the gauge is determined by ocular inspection. While the gauge shown determines whether the piece of work will go into place or not when the machine or device that it is intended for is assembled, it does not determine whether it is too small to satisfactorily perform its allotted function. But, if another gauge is made similar to that shown in Fig. 29 (*b*), preferably on the same block, and if this second gauge is made slightly below the minimum size permissible, a limit gauge would be thus obtained. In that case, if the work enters the smaller gauge, it is proved to be too small; if it refuses to enter the larger gauge, it is shown to be too large; but if it enters the large gauge and does not enter the small one, it is correct in size within the amount of variation existing between the large and the small gauge.

In order that the work may readily be removed from the gauge, a large hole may be drilled through the block *b*, as shown in the illustration. The work is then pushed out of the gauge either with the fingers or with a small wooden or metallic rod.

51. A somewhat different case of gauging is shown in Fig. 30. In this instance, the object of gauging is to determine whether the center-to-center distance *a* of the holes is correct within the predetermined limit of variation. The simplest kind of gauge for this work is a plate with two fixed gauge pins of correct diameter placed the required distance apart. Such a gauge is open to one objection, however. If

the pins happen to fit the holes in the work rather closely, it is quite difficult to remove the work from the pins after it has been forced on, since it is not an easy job to draw the

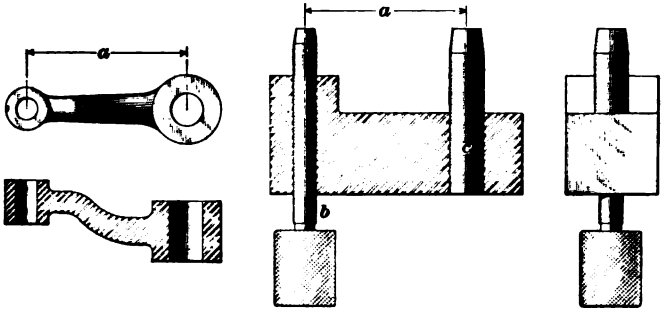


FIG. 30.

work off squarely. This objection can be overcome by making one of the pins, as *b*, movable; it is then to be made a good sliding fit in the body of the gauge. The other pin, as *c*, is rigidly fixed. Withdrawing the movable pin allows the work to be readily drawn off the fixed gauge pin.

52. A pin gauge of the construction shown in Fig. 30 apparently forms at the same time a limit gauge. Referring to Fig. 31, let *b* and *c* be the gauge pins. Let them be placed 1.18 inches from center to center. Assume that the holes in the work, by previous gauging, have been proved to be larger than .449 and smaller than .451 inch. Then, obviously, the gauge pins must be made small enough to enter the holes when their size is the smallest permissible, i. e., .449 inch. Now, assuming that the holes are larger, say .451 inch, the work will go over the gauge when the side of the holes

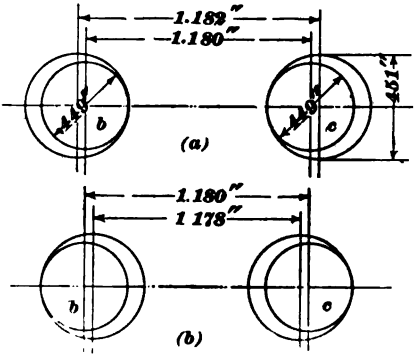


FIG. 31.

touches the inside of the gauge pins, as in Fig. 31 (*a*), or the outside of the gauge pins, as in Fig. 31 (*b*), and also when the center-to-center distance, for the size of hole assumed, varies between these two extreme positions. In the first extreme position, the center-to-center distance will be 1.182 inches; in the other, it will be 1.178 inches. We thus obtain as the extreme limit of variation 1.182 inches — 1.178 inches = .004 inch, or, as the limit of variation in the size of the holes is .451 inch — .449 inch = .002 inch, a variation double that which is permitted in the size of the holes.

Now, suppose that the holes in the work happen to be the same size as the gauge pins. Then, the work will not enter at all unless the center-to-center distance of the holes coincides with that of the guide pins. If it varies but .001 inch from it, the gauge will not go into the holes; the work may thus appear worthless when in reality the holes may be located quite within the permissible limit of variation.

Now, suppose that the gauge pins are made smaller than the smallest size of hole permissible, say .002 inch, thus making their diameter .447 inch. Then, if they are placed 1.18 inches from center to center, the work will go over the pins if the center-to-center distance of the holes varies between 1.178 and 1.182 inches, if the holes are the smallest permissible size. If, however, they are the largest size allowable, as .451 inch, the work will go over the gauge pins if the center-to-center distance varies between 1.176 and 1.184 inches.

53. Having seen that reducing the diameter of the gauge pins results in an increase of the range of variation within which the work will pass over the gauge pins, we will now investigate how this range can be reduced.

The most obvious way is to reduce the limit of variation in the size of the holes. Suppose that the holes being nominally .45 inch in diameter, we place their limiting sizes at .4495 and .4505 inch. If the holes are small, say below 1 inch, there is not much difficulty in reaming them within this limit. Then, if the gauge pins are made .0005 inch

below the smallest permissible size of hole, or .4495 — .0005 = .449 inch, the work will go over the pins if the center-to-center distance of the holes in the work varies between the limits of 1.1785 and 1.1815 inches; that is, if it varies .0015 inch either way from the nominal center-to-center distance.

The limit of variation in the center-to-center distance of the holes that can be detected by a pin gauge can be further reduced by constructing one of the pins, preferably the fixed pin, in such a manner that it can be centrally expanded to fit the hole in the work. If this is done, the limit of variation in the center-to-center distance within which the work will go on the gauge will be reduced to one-half of that obtained otherwise.

A satisfactory way that may be suggested for gauging the center-to-center distance of holes is to make both pins adjustable to the size of the hole; one pin is then rigidly fixed and the other is mounted on a slide provided with a vernier that reads to zero when the center-to-center distance is correct. If the work is placed over the pins and both pins are then expanded to fit the holes, the amount that their center-to-center distance differs from the nominal distance is then read off directly by the aid of the vernier. Such a gauge is rather expensive; the circumstances of each case must determine if the investment is advisable.

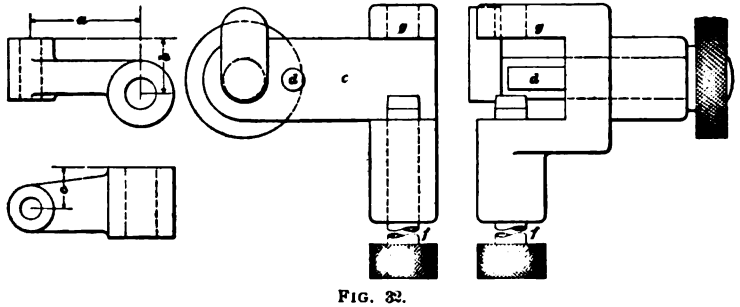


FIG. 32.

54. In Fig. 32 is shown a suggestion for a gauge intended to gauge the center-to-center distance *a* of holes at a right

angle to each other. At the same time, it is intended to gauge the distances *b* and *c* between the faces indicated and the axes, or center lines, of the holes. A gauge pin *d* may be made to fit closely in the hole in the left-hand boss; this pin is inserted at a right angle to the surface *e*. The movable gauge pin *f* fits the hole in the right-hand boss; it is placed with its center line parallel to the surface *e* and the distance *b* from it. Then, if the work is placed over the gauge pin *d* and then held or clamped with the clamping bolt shown against the surface *e*, while the upper surface of the right-hand boss is against the stop *g*, it will be seen that the gauge pin *f* cannot enter and pass through the hole of the right-hand boss unless the distances *a*, *b*, and *c* are correct.

DIES AND DIE MAKING.

(PART 1.)

DIES AND PUNCHES.

GENERAL FEATURES.

DEFINITIONS AND EXPLANATIONS.

1. Meaning of the Term Die.—Dies are devices for cutting, forming, or otherwise manipulating metals and other substances. They are ordinarily grouped in pairs and act together, being moved toward one another, usually under heavy pressure. One die alone could not do the work; there must be something to press the material into it, and that something is the other die, its mate. Such a pair of tools is sometimes called *a die*, but this term lacks definiteness and mistakes might occur when designating one or the other tools in question. Although somewhat awkward, the term *a pair of dies* seems to be the better name, notwithstanding that in some instances three separate members, or possibly four, may be necessary, as in the case of double-action and triple-action dies.

Where one die is smaller than, and enters, the other, as in punching, cutting, and sometimes in forming, the entering part is usually called the **punch,** and the part into which it enters the **die.** Very often the name *plunger* is applied to the punch, while the die is not uncommonly called the *matrix.* Where either has some peculiar shape or some

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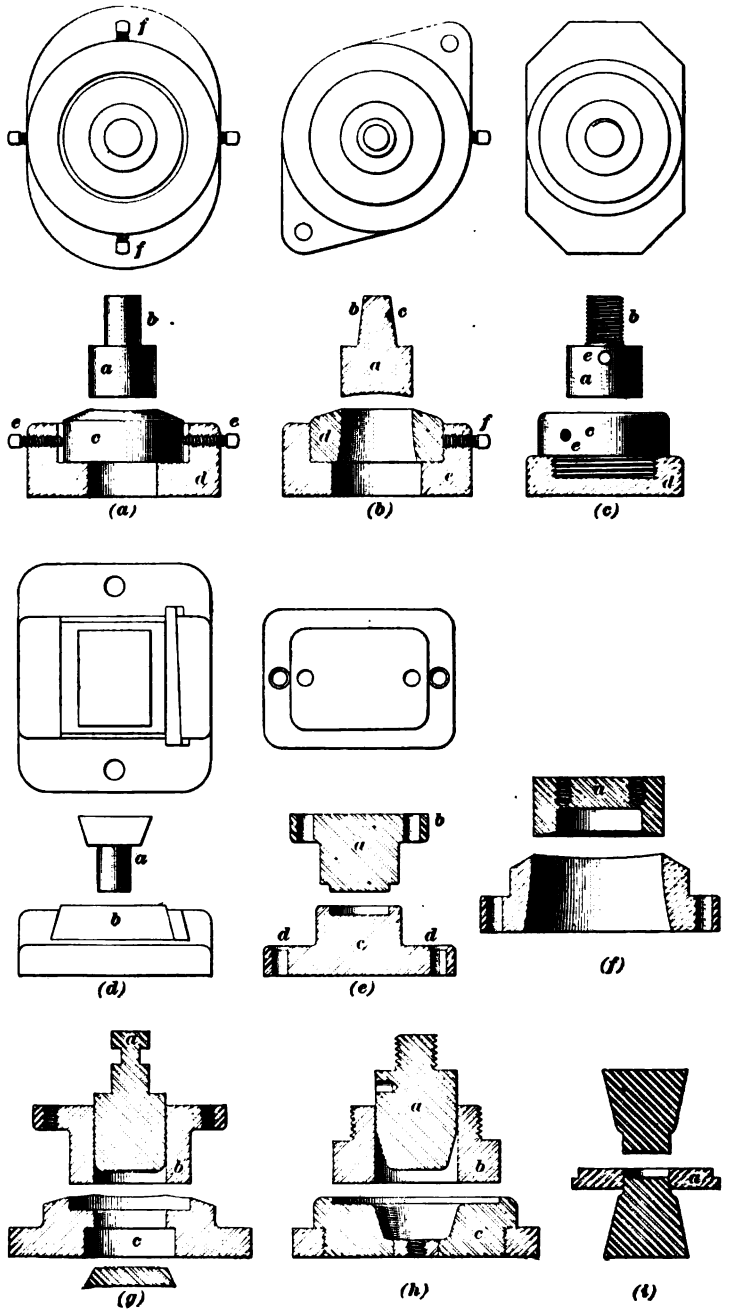


FIG. 1.

special function to perform, the workmen operating it may give it a special name, but the names given are now in almost universal use.

2. The Ram and Bed.—Before classifying dies into special kinds, it will be well to consider some features that are common to almost any kind, such, for instance, as the various methods of fastening the punch to the *ram*, and the die to the *bed*, of the press in which they are to be operated. The **bed** is the solid, or anvil, part of the machine, on which the die is fastened, while the **ram** is the moving member usually descending from above, to which the punch is attached. Occasionally, however, the ram works from below and may be so enlarged at the top as to form a moving bed, while the stationary part of the press holds the upper die and is in such case termed the *head*.

3. Methods of Fastening Dies.—In Fig. 1 is shown a group of dies that may be of any of the various kinds, as far as the method of attachment is concerned. At (*a*) is shown a punch *a* with a cylindrical shank *b*, to be held by a setscrew or clamp in the ram, and a die *c*, adjustably held in a chuck *d* by setscrews *e*, *e*, the chuck having a flange *f* that may be gripped with clamps on the bed, or bolster, of the press. A **bolster,** in general, is a flat plate lying loose upon the bed, so that it may be adjusted laterally and clamped down in any desired position. Its purpose is to partly fill any space where the dies happen to be thin, and also to act as a bridge over any hole in a press bed, especially when small dies are to be attached.

At (*b*) is shown a punch *a* with a conical shank *b*, to be held by a setscrew in the countersink *c*. The die *d* is cylindrical and is held in the chuck *e* by the setscrew *f*, which fits into a countersink similar to that shown at *c*, in the punch. The chuck has holes in its flange, through which tap-bolts may be screwed into the bolster.

At (*c*) is shown a punch *a* with a screw thread *b* that is to be screwed into the ram, and a die *c* screwed into the chuck *d*. The flange of the chuck is held by clamps to the

bolster. Both the punch and die have holes *e* for a spanner, with which they are to be turned. A wedge fastening is shown at (*d*), where both the punch *a* and the die *b* are of a dovetail section, the punch to be held in the ram and the die in the chuck by wedges.

At (*e*) is shown a punch *a*, to be held to the ram by tap bolts through the flange *b*, and a die *c* held direct to the bolster, or bed, by tap bolts running through the holes *d*, *d* and screwing into the bolster.

A pair of cutting dies, as shown at (*f*), may be held in a similar manner. No flange, however, is used on the punch *a*, but tap bolts from above screw into the body of the punch.

A pair of triple-action dies is shown at (*g*) with the shank *a* of the punch so made as to be loosely held in the press plunger by a special latch, while the blank holder *b* is held to the flange of the ram by tap bolts. The die *c* is clamped to the top of the bolster, and the matrix below is held in the lower plate of this special bolster by a dovetail and wedge.

At (*h*) is shown a pair of double-action dies with punch *a*, blank holder *b*, and die *c*, all made to screw into place.

A pair of coining dies are shown at (*i*) with their collar *a*. They are of conical shape and are both held by adjustable setscrews in a manner similar to that for holding the chuck shown at (*a*). The collar is inserted in the bolster of the press and held by a clamping ring.

4. Comparison of Fastenings for Dies.—Obviously, various other devices may be used, the object being merely to fasten rigidly one of the dies so that it cannot shift while at work, the other being adjusted exactly under it by trying them together, and then both being securely fastened to the press. The old-fashioned way was to have the adjustment with the setscrews, as shown at Fig. 1 (*a*). The pressure of these setscrews is apt to spring or twist the die out of shape, especially if it happens to be in the form of a somewhat thin ring. The most modern system of clamping a die down on a flat surface, after it is located in the proper position, is shown at (*c*) and (*e*).

It must not be understood that the various methods of fastening the punch and die are necessarily arranged in pairs in the order given, as any of the upper fastenings may be combined with any of the lower ones. Neither are lower dies always held in chucks, but they are often complete in themselves with their flanges. There is an economy in the use of chucks where the dies are small and where there are many nearly of a size. In some cases upper chucks are used, secured to the ram by any one of various methods. Small dies or punches may then be fastened in the chucks.

5. Forms of Dies.—In order to gain a general idea of the nature and almost infinite variety of the forms constructed by the use of dies, one should study the following

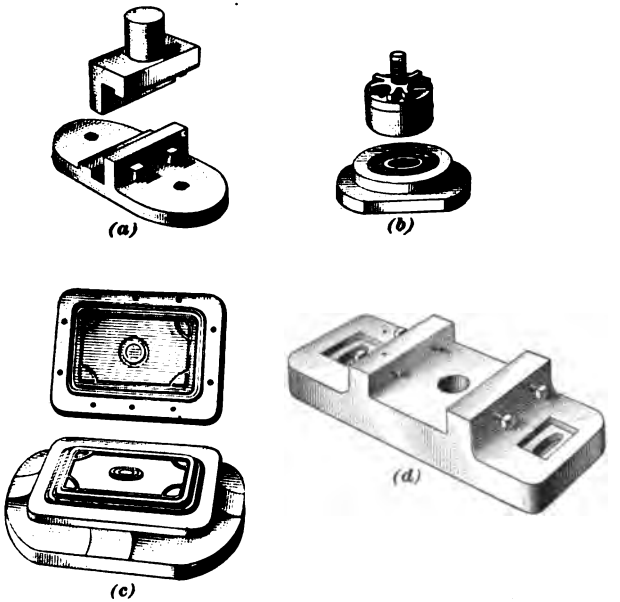


FIG. 2.

illustrations, together with the pressed-metal forms that he may see every day. Thinking of and studying the forms, with the question of how they can best be produced continually before him, will be of great value. Some of the

common varieties of these tools are shown in Fig. 2. A shearing punch and die are shown at (*a*), which is well adapted for cutting off bar metal or making short, straight cuts. The pair of dies shown at (*b*) is for the purpose of making fruit-can tops, while the combination square dies shown at (*c*) would make very good sardine cans. At (*d*) is shown a die chuck for the purpose of holding the die in place.

The range of useful articles that are made by dies is very great, and their value is often much greater than the cost of their production. Fig. 3 shows some of these shapes. A piece of ornamental ironwork for buildings is shown at (*a*).

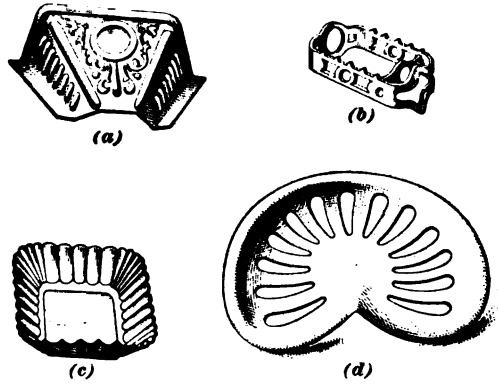


FIG. 3.

The bicycle pedal shown at (*b*) is made up of several stamped pieces, while the dish shown at (*c*) is made of a single piece of metal. At (*d*) is shown the ordinary reaper seat, which is now used so extensively instead of those that have been cast. It is made from a single piece of metal

CLASSIFICATION.

6. Names of the Classes.—Dies may be roughly classified according to the operations that are sometimes performed upon a single piece of metal, as *cutting*, *forming*,

curling, *drawing*, and *coining*. This classification is wholly functional, and a variety of subclasses may be derived from them, the names of which are also functional. Thus, in the **cutting** class, there are chiseling, shearing, and punching dies, the latter being really shearing tools with the edge extending all the way around, instead of part way, as with shear blades. There are also repunching or drifting dies, which are really more in the nature of the paring tools of the machinist, the process being somewhat analogous to planing or slotting.

In the **forming** class, besides forming dies proper, there are bending, embossing, and seaming dies. The seaming dies are often in the form of horn dies, where the work is placed upon a cylindrical or prismatic horn, and has its seam at the jointed side tightly mashed.

The **curling** class is generally used in a preliminary operation, or with other dies in a series, and is for the purpose of turning over or curling edges and rims of various articles.

In the **drawing** class are the single-action and double-action processes, also various forms of redrawing, with diameters decreasing from the original operation. There are also analogous operations, such as wire drawing and spinning, which, not being performed by presses, need hardly be further considered here.

In the **coining** class are the analogous operations of *drop forging* and *squirting*. The latter process is the one by which are made the soft-metal collapsible tubes that are so largely used for holding artists' paints and other semi-liquid substances. Both this and coining, as well as some others, are notable instances of the flow of solids.

Additional complication in the names of these tools are caused by the use of **combination dies,** which are usually known by this name, although sometimes called **compound dies.** In general, they combine the functions of cutting and forming, cutting and drawing, or cutting and embossing, as used largely in the making of shallow or deep tops and lids for fruit cans, blacking boxes, kitchen utensils, etc.

The term *compound* will be used in this Section for dies combining similar processes, as several cutting, or several forming operations.

A still further ambiguity in the naming of these tools occurs with the various kinds of **gang dies.** The adjective gang alone does not mean anything very definite, but is generally applied to a group of punches and dies fastened in common into their respective plates. Sometimes these are all alike, as in gang-cutting dies, where a large number of similar pieces are to be punched at the same time. In other cases the pieces may be different, or some of the dies in the gang may be cutting dies, and some forming or embossing dies. Certain forms of gang dies are known as **progressive dies.** These are generally used for cutting, but sometimes for cutting and forming, at successive operations, on the same piece of material, as in cutting washers, cutting and embossing tobacco tags, etc. For cutting an ordinary washer, for instance, a hole is punched at the end of a strip of iron, which is then passed to a second position, where a pilot pin, projecting from the bottom of a larger punch, enters the hole previously made and centers it. Meanwhile, the punch descends into its die and cuts the exterior periphery of the washer around the hole in question; at the same time the punch which made that hole is descending into its die and punching a new hole farther along the strip. This in its turn becomes the nucleus, so to speak, for the next washer, and thus a complete article is produced at each stroke of the press after the first one, until the strip of metal is exhausted. In general, care must be taken not to make the names of dies too positive without specifying what they are to do.

QUALITY AND DESIGN OF DIES.

7. Temper Required.—The popular idea of a die is that it must be of the best quality of steel, hardened to the greatest degree that it will stand without crumbling. This is true for cutting dies for thick and hard metals, for many

kinds of embossing dies for doing fine work, and for coining dies; for cutting soft metals, say, under $\frac{1}{16}$ inch thick, and even tin plate, sheet iron, and annealed low-carbon steel, one of the dies may be left moderately soft, with an air temper only. When the edges of a soft die get dull it may be hammered cold and upset to bring the cutting edge to place again. After this has been done, the other die, which meanwhile has been ground upon the face to make it sharp, is forced through or over its mate, shaving the two dies to a perfect fit.

In various forming dies, especially where the work does not have vertical edges, the working parts may be of untempered steel, usually of high carbon, to get greater hardness and durability. In still other cases the working surface of forming, and especially of drawing, dies are made of a good quality of cast iron. This is especially true where the cup-like shapes, such as household utensils, to be formed or drawn, are of an approximately spherical or conical form, and where the exact diameter does not need to be maintained. In other cases, wrought iron or mild steel is good enough for working surfaces, sometimes being case-hardened. There is economy in not heating any part of a die after it is once brought to shape, either for hardening or case-hardening, for in every hardening operation there is a risk of temper cracking, and every heating distorts the metal. Hence, in cutting dies where they must be hardened and the fit must be good for thin metals, some grinding should be done after the hardening. This is easily done with round and elliptical shapes, where the grinding can be done in the lathe, but with irregular shapes it is often quite difficult.

8. Degree of Accuracy Required in Dies. — There are many degrees of accuracy in tools of this class, according to the quality of work needed. In deciding the material, hardness, and general quality of a pair of dies, the amount of probable production must be ascertained. If but a small number of articles are to be made, the cheapest possible dies

that will make them properly should be selected. If, on the other hand, large quantities are to be produced, and especially if they must be very uniform in dimensions, it is good economy to spend any amount of time and money necessary upon the dies in order to make them as perfect as possible in every detail; furthermore, careful study should be given to make them of composite design, so that the parts most liable to wear can be cheaply replaced, and thus avoid making entirely new dies. Sometimes, to lessen the risk of cracking and to allow straightening the dies, so-called *composite steel bars* are used; these are soft iron for two-thirds of their thickness, while the other one-third is steel, which is welded on.

Another point to be decided in the case of cutting dies is how closely they shall fit each other. For thin metals, the punch should enter the die with a good sliding fit. For punching bar and plate iron, it is customary to make the punch loose in the die to an amount equal to at least one-sixteenth the thickness of the metal. Dies made in this way are more durable and require considerably less pressure than when fitting each other closely. Indeed, it has been found by the well-known Seller's experiments that the least resistance in punching occurs when the punch is smaller than the die by one-fifth of the thickness of the metal. This, however, usually leaves the holes with too much taper. In punching boiler iron and various forms of bar metal for ships, bridges, buildings, etc., the amount of taper allowed in the holes is usually from $\frac{1}{32}$ inch to $\frac{1}{16}$ inch, which does no harm with holes that are in any case loose upon their bolts or rivets.

9. Attachments Used on Dies.—Many of the ordinary attachments to dies, which may or may not be applied, and which are oftener needed for cutting dies than any others, are various forms of **gauges** for locating the work, and **strippers** for preventing it from rising. In shearing, a device termed a **hold-down** is often used. This is simply an arm extending out loosely over the top of the bar or

plate to be sheared to keep it from tipping, especially when the shear blades are worn and have dull edges.

10. Die Making in General.—There can be no fixed and definite rules for die making, as is the case with some of the other products of the toolmaker. While in some cases each die is simply a piece of steel of the proper shape, in other cases much careful designing is needed to get the best results in economy and durability. The choice of widely differing methods is often open to the die maker, even in the production of a single article.

CUTTING DIES.

PLAIN DIES.

11. The **plain die** shown in Fig. 4 is made up of four distinct essential parts, which are: the hardened and tempered block *a*, which does the cutting; the **stripper plate** *b*,

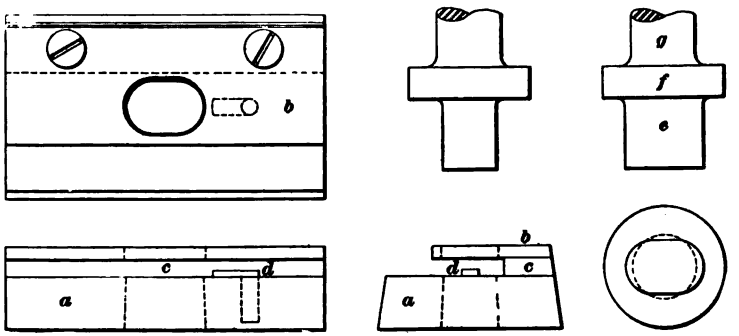


FIG. 4.

which strips the stock from the punch; the **guide strip** *c*, which guides the stock; and the **gauge pin** *d*, which gauges the location of the holes punched in the stock. By *stock* is here meant the material to be punched, which in

most cases comes in long parallel strips, and is generally fed by hand or automatically.

The punch consists of not less than three essential parts, which are: the **punch** proper *e*, which does the cutting; the **collar** *f*, which takes the thrust; and the **shank** *g*, by means of which the punch is attached to the ram of the press. These three parts may be one piece, as shown, or they may be separate pieces united by suitable means to form the punch.

Dies like the foregoing may be intended to pierce a hole of a given shape through the material, in which the **punching** or **wad** is the waste material, or **scrap,** as it is commonly termed, or it may be that the punching is the article desired, in which case the remainder of the stock is the scrap.

12. Self-Centering Punch.—Dies intended chiefly for producing holes do not always need a gauge pin; in many cases, the material in which the holes are to be punched is center-punched at the point at which the hole is to be located; the punch may then be provided with a small conical point *a*, Fig. 5, which enters the center-punch mark and thus centers the work. When holes are to be punched equidistant, a gauge pin will in many cases be found of great advantage, inasmuch as by it the laying out of the holes on the work can be avoided. The conditions that exist in each case will readily determine whether a gauge pin can advantageously be used or not.



FIG. 5.

13. Spiral Punch. — Fig. 6 shows a punch the cutting edge *a* of which is made in two or more spiral curves, instead of being in a single plane, as in the one shown in Fig. 5. This

is supposed to make it cut more easily, but with a small hole in thick metal the effect cannot be very great. The *dip* or *shear* given to large punches working in thin sheets enables the cutting to be performed progressively; that is, one end is cut clear through before the other end commences to cut. This punch is very cheaply mounted by the shank *b* and coupling *c*, which can also be used to hold any number of other punches. It is of a shape that is cheaply made and has in it the least possible material. In Fig. 6 the work is shown at *d* and the stripper plate at *e*.

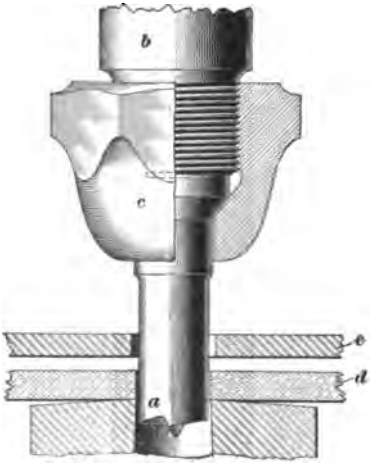


FIG. 6.

A piece already punched may have other punching done within the space enclosed by its bounding edges by means of a second die, thus accomplishing the required result in two separate operations.

14. Gauge Die.—The dies for the second operation may be arranged as shown in Fig. 7. The punching, or **blank,** as it is often termed, turned out by the first operation is shown at (*a*); this is to be pierced by the holes *a* and *a'*, see (*b*). The die is pierced with properly located holes of correct diameter and the punch plate is provided with two punches, as *b* and *b'*. The sectional view of the die is taken on the line *A B*. The guide strip and the gauge pin of the first operation die are here replaced by a **gauge plate** *c* attached to the die. This is fastened in such a position that it will properly locate the blank in relation to the holes in the die.

The gauge plate has an opening of the same shape as the blank, but sufficiently larger to allow it to be freely

inserted. If a stripper is attached to the die, it will not only be difficult to insert the blank in the gauge plate, but it will also be difficult to remove it. It is also difficult to keep clean the opening in the gauge plate. To overcome these objections, the stripper *d* may be fitted to the punch, being

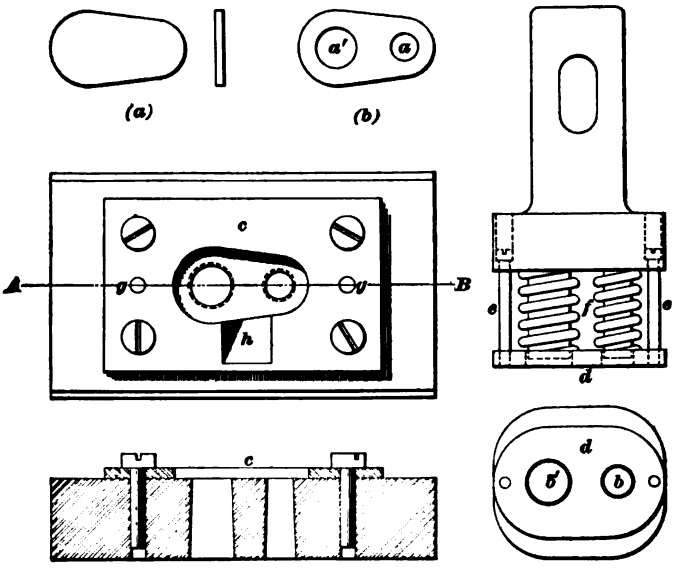


FIG. 7.

attached by means of two heavy screws *c*, *e*, which permit it to move upwards. Heavy coiled springs *f* hold the stripper in its lowest position, which is so governed by the length of the screws that its lowest surface projects slightly beyond the faces of the punches.

Imagine the die to be in place and that a blank is placed in the opening of the gauge plate. Then, if the punch descends, the stripper comes in contact with the blank and remains stationary. As the punch continues to descend, the coiled springs are compressed; the punches pass through the blank, and when they return, the springs, by acting on the stripper, strip the blank from the punches.

In order that the gauge plate may not shift, it is doweled to the die by means of the dowel-pins g, g, and is held down by flat-headed or fillister-headed screws. To allow the blank to be readily removed from the gauge plate, a part of the circumference of the opening may be beveled, as shown at h. A wedge can then be used for prying out the blank. For rapid work, it may be advisable to devise some lever arrangement, operated by some moving part of the press, that will automatically throw the blank out of the gauge plate after punching. The gauge plate is often made so that it encircles about one-half the blank, which is then pushed against the gauge, and after punching can be removed by being slipped out. This arrangement is somewhat objectionable on account of the liability of the blanks moving slightly away from the gauge before the punch strikes it.

By using a second die fitted with a gauge plate the holes can be located very closely, so that all punchings will be very nearly duplicates. Since, however, this requires a second operation, the time cost per punch will be more than double what it would be if the blank and the holes could be produced in one operation.

PROGRESSIVE DIES.

15. Progressive, or **gang, dies** are intended to remedy the defect of excessive time cost, but some designs are open to the objection that, while they accomplish their primary object, they cannot be relied on to produce duplicate work, since they depend largely on the straightness of the stock and the skill of the press operator to produce good work. A common design is shown in Fig. 8, which is arranged to punch the same piece shown in Fig. 7 (b). For this purpose, the die contains three holes: a and a' are for punching the holes within the blank and b for punching the blank itself. The stripper is shown at c and the gauge pin at d. Two guide strips e, e guide the stock between them.

When starting a strip of stock, it is inserted at the left of the die, below the stripper, and pushed forwards until its end rests against the gauge pin at *d*. The punch then cuts out one blank that has no holes in it, which is thrown away; *A* and *A'* at the same time punch the holes *a* and *a'*. The stock is then pushed along until the left-hand edge of the large punched hole in the stock comes against the gauge pin. The holes *a* and *a'* in the stock are now in their correct positions above the opening *b* in the die; as the punch descends, it cuts out a finished punching at *b*, and at the same time cuts a new pair of holes *a* and *a'* through the stock. Now, assuming that the die is correctly laid out and the gauge pin correctly located, it is

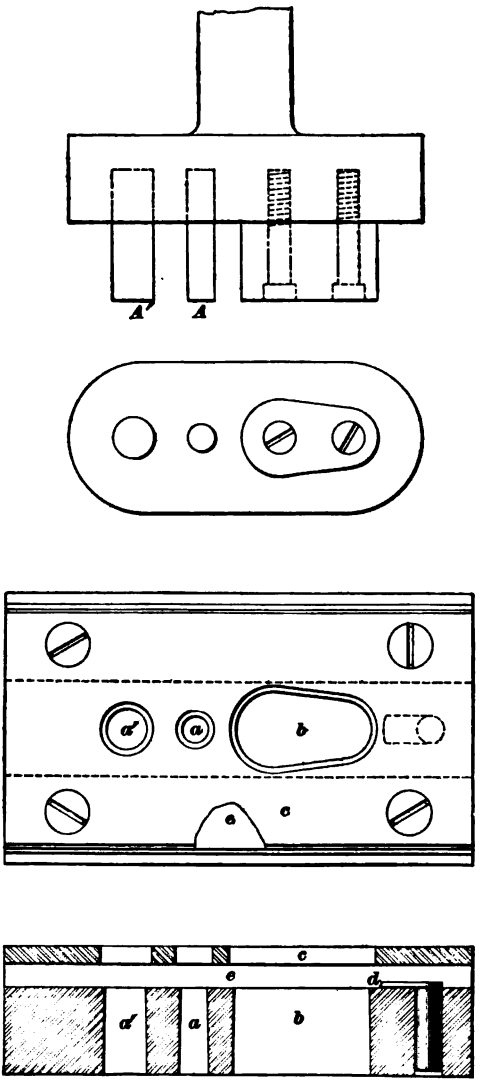


FIG. 8.

readily seen that if the operator fails to push the stock against the gauge pin, the holes will not be correctly located in the blank. Hence, although when in skilled hands, this design of dies will produce fairly accurate work, it cannot be relied on to make exact duplicate pieces. Whether this consideration is of sufficient moment to prevent its use must be decided upon the merits of each case.

In the design, two guide strips are placed the required distance apart to insure the stock being properly fed in; these can be used, however, only when the stock is uniform in width and straight. When it is not, only one guide strip can be used, and the operator must always push the stock firmly against it. Should he fail to do this every time, the holes will be improperly located in some of the punchings.

In some cases one of the guides has springs back of it, which hold it against the stock, and so hold the latter against the other guide.

16. Self-Centering Dies.—Fig. 9 shows a design that is intended to overcome, to a large extent, the defects of ordinary progressive dies. The piece to be punched is shown at (*a*). In order that the stock may be properly centered in case the operator should fail to push it against the gauge pin, the punch is provided with a beveled pilot pin *a*. The upper cylindrical part of the pin is made an easy fit in the circular hole that is already punched in the stock and is so located on the punch *c* that its center line coincides with the center of the hole in the punching.

This style of die will produce duplicate work within quite a small limit of variation, but the pin must be a loose fit in the hole within the punching, so that the latter will not stick to the punch. The limit of variation within which the holes will be located inside of the punching is equal to the difference in the diameters of the pin and the hole. The design shown is open to one objection, however. Should the punch come down when the stock is not in such a position that the pin is fairly over a hole, the pin is pretty sure to be

broken. But this objection, if circumstances permit it, may be overcome by making the pin movable in an axial direction

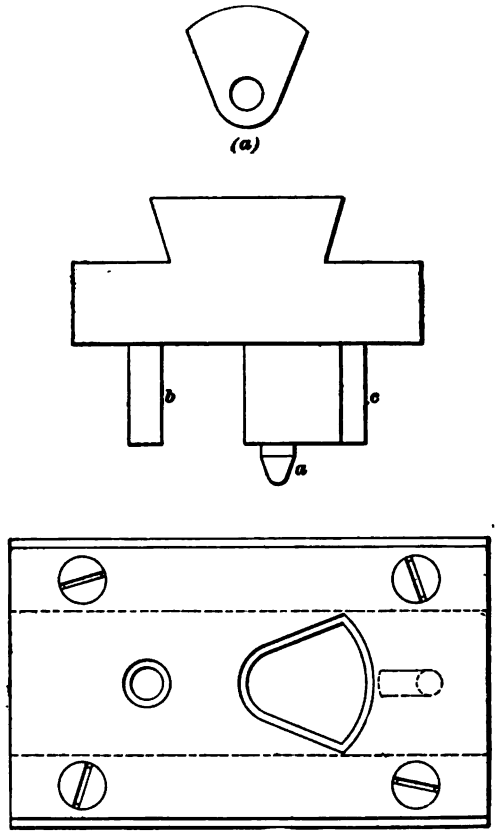


FIG. 9.

and providing a helical spring that will be compressed by the receding of the pin in case it strikes solid stock.

COMPOUND DIES.

17. The Construction of a Compound Die.—When punchings pierced by holes must be exact duplicates of one another, so-called compound dies are necessary. These

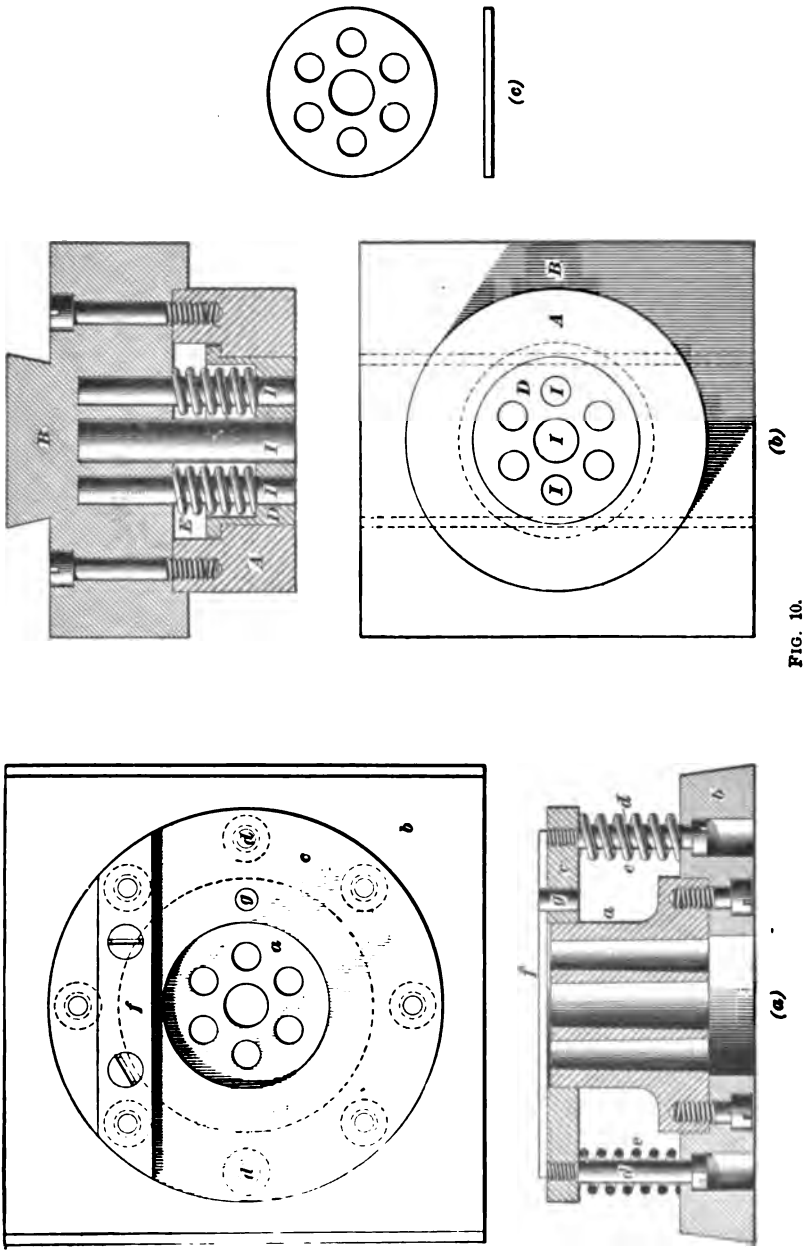


FIG. 10.

differ from plain and progressive dies in that both the upper and the lower die have the punch and die cutter and a stripper. Compound dies do not depend in any way on the skill of the operator, and will make all punchings exactly alike, as becomes apparent when their construction is studied.

An approved design for compound dies is shown in Fig. 10. At (*a*) is shown a vertical section and a plan view of the lower die; at (*b*) is shown a vertical section and a bottom view of the upper die; while at (*c*) is shown the complete punching, which is produced in one operation. Referring to (*a*), the tool-steel block shown at *a* is both a die and a punch. It is fitted to a recess cut into the plate *b* and is attached to it by means of the screws shown. The block *a* is surrounded by the axially movable stripper *c*, confined as to its uppermost position by the heads of the screws *d*, *d*, which engage shoulders within the base. The stripper is held up by heavy helical springs *e*, *e*. The guide strip *f* and gauge pin *g* are fastened to the stripper.

The upper die differs from the lower in that the punch block *A* and the punches *I*, *I* are separate, but they are each rigidly fastened to the plate *B*, which fits the ram of the press. The stripper *D* fits in the block and surrounds the punches; it is axially movable, being confined as to its lowest position by a shoulder and held down by helical springs *E*, which in this particular case surrounds the punches. The outside of *a* in (*a*) fits the inside of the *A* in (*b*), and *I*, *I* fit the holes in (*a*).

18. The operation of a compound die is as follows: The stock having been placed against the guide and the gauge pin, the upper die in descending first depresses the lower stripper until the stock touches the upper surface of *a*. As the upper die continues to descend, it punches the outside of the punching and the inside holes at the same time; the punching passes into the upper die, pushing the stripper *D* upwards. When the upper die moves up again, the lower stripper *c*, under the influence of its springs, strips the stock from *a*; at the same time, the upper stripper *D* ejects the punching from the upper die. The scrap punched from

within the punching discharges down through the holes in the lower die, which are given clearance to facilitate its descent. No clearance is given to the hole within the upper die.

Compound dies by reason of their construction will produce the most accurate work, but are quite expensive as far as first cost is concerned; hence, if accuracy is not a paramount consideration, progressive dies may be used advantageously; but if accuracy is absolutely essential, compound dies should be used. Such dies are largely used for armature disks, and for clock and watch wheels. These small dies are usually mounted in subpresses.

LAYING OUT DIES.

19. Economy in the Use of Stock.—Before a die is laid out, i. e., before the outline of the hole and the exact location of the gauge pin can be marked on the surface of the lower die, the toolmaker must determine which is the most economical way of punching the stock. Then, he must so lay out the die that the greatest number of punchings can be obtained from a given weight of stock, in order to reduce the waste to the lowest figure. This is a matter that requires a great deal of judgment. It has been found to be a good plan to cut a few pieces of paper to the required outline of the punching; then, by arranging them in different ways, one is usually able to determine quite rapidly the most economical system of locating.

Cases illustrating right and wrong ways of punching stock are shown in Fig. 11, where *a* represents the stock and *b*, *b* the holes remaining after the punching has been done. Referring to (*a*), the strip of stock is seen to have passed but once through the press, leaving an enormous amount of waste. In (*b*) the gauge pin was so located that there was sufficient stock left between each pair of holes, after passing the strip entirely through the press, to allow it to be reversed and passed through once more, punching out most of the

metal that remained between the holes after the first punching. Inspection shows that by arranging the operations to

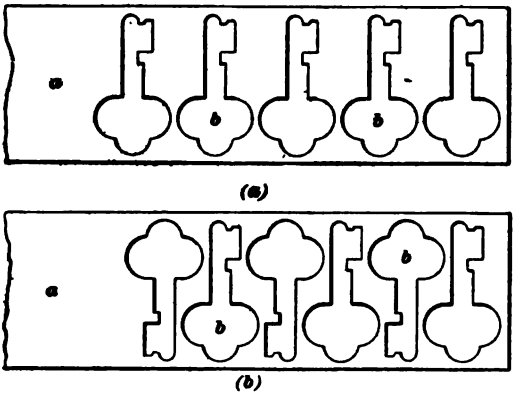


FIG. 11.

take place as in (*b*), a great many more punchings can be obtained, and that, therefore, this method is the more economical.

An appreciable economy can often be obtained by the judicious selection of a proper width of stock. Thus, in

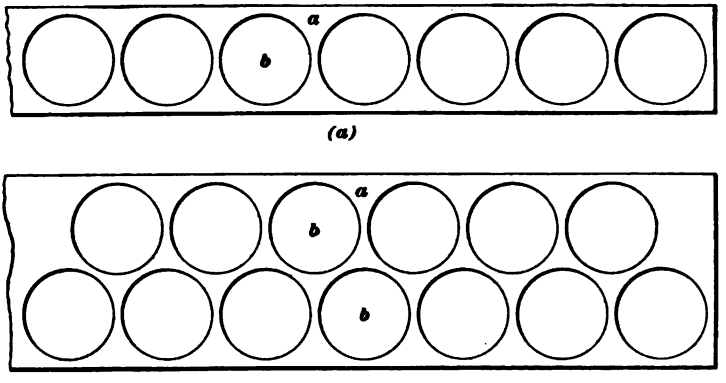


FIG. 12.

Fig. 12, supposing *a* to represent the stock, and *b* the holes left after punching, it can be seen that by using stock wide

enough to punch staggered holes, as in (*b*), less material will be required for a given number of punchings than is needed when using a narrow strip, as in (*a*). By measuring, it will be seen that the wide stock is not twice as wide as the narrow, although it will practically give twice the number of punchings for equal lengths of strips. Paper or tin-plate models having the required outline can also be used advantageously for finding the best width of stock.

20. Position of the Gauge Pin.—The part of the gauge pin that forms the stop for the stock determines by its position the amount of stock that remains between the punched holes. This amount at the narrowest point between adjacent holes should, in general, never be less than the thickness of the stock, and may be slightly more for very thin material. It should not be forgotten that the punch, in passing through the stock, tends to draw, and actually does draw, some of the surrounding material toward its cutting edges. If there is too little stock around its periphery, it is liable to draw it inwards into the die, which is likely either to jam or to break the punch and die, or to make a ragged punching.

21. Laying Out a Simple Die.—To lay out the block of a steel-bar die, the upper surface is finished smooth by filing or grinding, and then coppered by using a solution of of one part of bluestone (sulphate of copper) and ten parts of water. Have the surface absolutely free from grease, and cover it lightly with the solution. In a few minutes this will have dried; a very thin film of copper will be found deposited on the surface, and will adhere quite firmly to it. The object of coppering is to make fine lines more plainly visible by the contrast in color between the steel and the copper. The outline of the hole is now laid out by scribed lines in the same position in relation to the guide strip that it is to occupy in relation to the edge of the stock. A center for the gauge pin is then marked at a sufficient distance from the outline of the hole to leave ample support to the cutting edges. The distance between the opening and

the gauge pin against which the stock is pushed is readily determined from the paper models laid on the stock. Measure on a line parallel to the edge of the stock the distance between corresponding points of the outline of the two nearest models that occupy the same position in relation to the edge; this is the distance that the end of the gauge pin must be from a point of the opening in the die that lies on a line parallel to the guide strip and passes through the gauge pin, and on the side of the opening farthest from the gauge pin. This distance having been marked on the die, the laying-out process is complete.

22. Laying Out Progressive Dies.—The holes first punched, which are to be located afterwards within the outline of the punching, must be in such a relation to the guide strip and the gauge pin that they will occupy their correct positions when the stock is against the end of the gauge pin. This is not a very difficult matter.

Let *A*, *B*, and *C*, Fig. 13 (*a*), be paper models of given outline that have been pasted on a piece of stock in the position in which it is believed the most economical use can be made of it. Then, parallel to the edge of the stock, draw any line, as *a a'*, through the models. The distance between corresponding points of intersection on models occupying the same relative positions, as between *c* and *d*, is the distance that any corresponding points must be apart on the die. When the outline of the hole within the punching is circular, the die may be laid out on the surface of the lower die by laying out the outline of the punching in the same position in relation to the guide strip that the model occupies in relation to the edge of the stock. If a model is given, this may be laid on the surface and the outline transferred by scribing around it. Also scribe through the hole within the model, and then, on the surface of the die, mark its center by a fine center-punch mark. If no model has been given, the outline and positions of the holes within the punching must be transferred from the drawing. Next, through the center-punch mark just made, as *c'*, Fig. 13 (*b*),

draw a straight line $e f$ parallel to the guide strip. On this line lay off the distance $c' d'$ equal to $c d$; the point d' will then be the center of the hole. By extending this method of laying out, the correct location of any point on the end of the gauge pin may be determined. If possible, the gauge pin should be so located that the act of pushing the stock against it will also force it against the guide strip. Suppose that it has been decided to locate the gauge pin within the

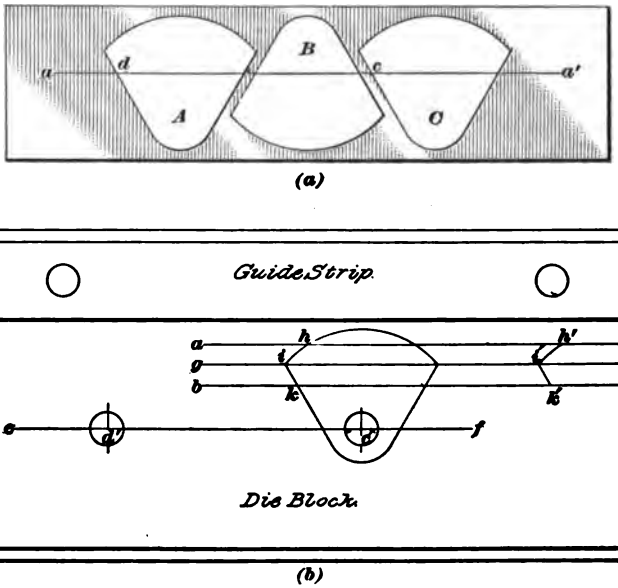
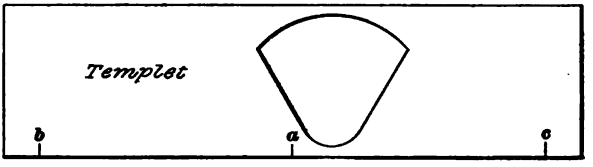


FIG. 18.

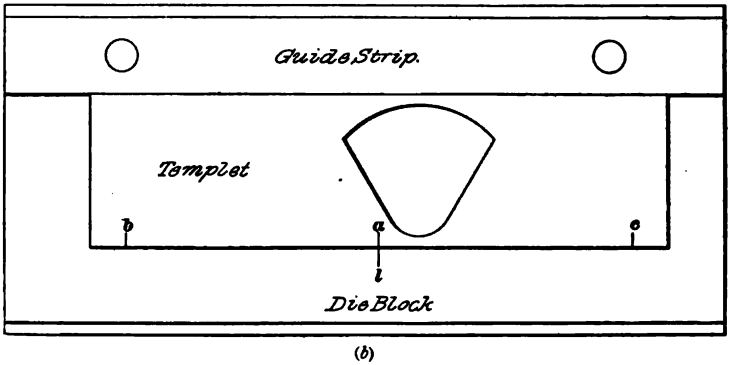
space included by the lines $a a'$ and $b b'$; then draw the lines $a a'$, $g g'$, and $b b'$ parallel to the guide strip. From the points where these lines intersect the outline, and farthest from the proposed location of the gauge pin, as h, i, and k, set off on them the distances $h h'$, $i i'$, and $k k'$ equal to $c d$. The points h', i', and k' are then points on the face of the gauge pin. It is not necessary to draw just three lines for this purpose; any convenient number, from one up, may be used.

23. A mechanical way of laying out the holes of a progressive die involves the use of a model and a templet. Both of these may be made advantageously of a piece of medium heavy tin plate; if this is not available, thin sheet steel or sheet brass may be used. Sheet zinc is still better, for if deep scribe lines are scratched in it the metal may be broken like glass after the diamond. By doing this, much filing may be saved.

Cut off a strip of the same width as the stock and cut a hole in it to exactly fit the outline of the model that has previously been made. Cut the hole in the same position relative to one edge that the punched holes are to occupy



(*a*)



(*b*)

FIG. 14.

relative to the edge of the stock. On this templet, in any convenient place on the edge, make a mark, as shown at *a*, Fig. 14 (*a*); then, to the right and left of it, lay off the distances *a b* and *a c* equal to *c d*, Fig. 13 (*a*). Now place the templet on the surface of the die and against the guide;

shift it to where it has been determined to place the largest opening, and, after clamping it, scribe through the opening. Make a mark, as *l*, on the surface of the die in line with the mark *a* on the templet. Shift the templet along the guide strip until mark *b* coincides with *l* and scribe through again. This scribed outline gives the location of the edge of the gauge pin. Next insert the model into the opening of the templet and shift it along the guide strip until mark *c* on it is in line with mark *l*. Now scribe through the holes in the model. The laying out is thus completed. It is a good idea to lay out the die on a piece of paper first; this will greatly aid in locating the openings centrally in the die.

24. Laying Out a Compound Die.—As far as the laying out of a compound die is concerned, there are no special directions needed. Probably the best practice is to make the lower die first; the gauge pin may be located on the stripper in exactly the same manner as with a plain die.

MAKING THE DIE.

25. Cutting the Openings in the Die. — The required outlines of the openings having been scribed on

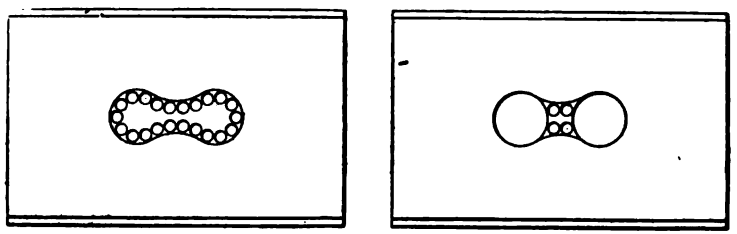


FIG. 15.

the die, they may be cut through by drilling a series of small holes close together, as shown in Fig. 15 (*a*), and then cutting out the metal between the holes with a narrow drift. The die is usually finished by filing to the scribed lines,

making the openings larger at the bottom, so that the punchings may drop out easily. The clearance given may be from 1° to 2°; to determine if the clearance is the same all around, the die maker frequently uses a die maker's square, which differs from the try square in that its blade, instead of making an angle of 90° with the stock, makes an angle of 90° plus the clearance angle. Obviously the blade of the square must be very narrow in order that it may be used for small openings.

When cutting the openings in the die, the toolmaker can often save himself considerable work, and make a better job at the same time, by forming circular arcs by drilling, counterboring, or reaming, if their formation by such means is possible. Referring again to Fig. 15, instead of drilling a series of small holes, two large holes may be drilled, as shown at (*b*), and clearance may then be given by reaming from the bottom with a taper reamer; considerable filing is thus saved, and, at the same time, the circular arcs at the two ends of the opening will be more nearly circular than filing could make them. The metal remaining between the two large holes can be cut out by drilling the small holes shown, and the die can be finished by filing the two reversed arcs to the scribed lines.

26. Filing Templet for Symmetrical Work.—Dies for work that has an axis of symmetry, as *a b*, Fig. 16 (*a*), can often be made advantageously by the aid of a hardened-steel **filing,** or **profiling, templet,** or *filing jig*, as it is sometimes called. Such a templet is shown in plan view at (*b*). Thin tool steel about $\frac{1}{32}$ inch thick is very good material from which to make this templet. Scribe a straight line *a' b'* on the templet, to represent the axis of symmetry. Then to one side of it lay out one half of the required outline, as *c d e f*. On the other side lay out lines, as *c g f*, sufficiently removed from the axis of symmetry to clear the other half of the outline. Next, on lines perpendicular to *a' b'*, mark the centers of the holes *h*, *h* equidistant from *a' b'*. These holes receive screws by means of

which the templet is to be attached to the die. Drill two small dowel-pin holes, as i, i', so that their centers lie on a' b'. Drill the holes h, h; cut out the opening in the templet, filing very carefully to the line c d e f, and then harden it. If the templet is hardened in water or oil, it will be sprung considerably; but if after being heated it is quickly placed between two planed cast-iron blocks, it will remain almost flat. Now lay the templet on the die and clamp them together. Using the templet as a jig, drill the dowel-pin holes, spot the location of the holding-down

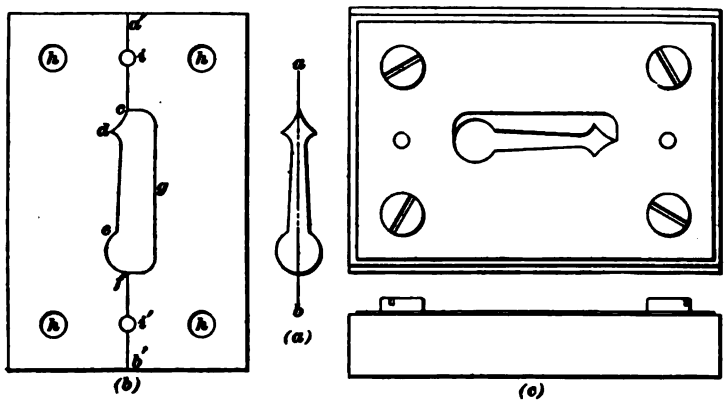


FIG. 16.

screws, and drill and tap holes to receive them. If circumstances permit, it is well to locate the holes h, h so that they can be used afterwards for attaching the guide strips to the die. Fit dowel-pins to the holes drilled for them, and place the templet over them. Mark one half of the outline on the die by scribing from the templet; then turn over the templet and scribe the other half. Rough out the opening in the die and attach the templet to it by means of the screws. One half of the outline can now be filed to the templet, which is then reversed as shown at (c), and the other half finished. Obviously, both halves of the outline will be exactly alike.

27. Giving Clearance.—Clearance may be given to dies in several ways. If the opening is rather small, it can usually be done only by filing; when the opening is large, a tapering milling cutter of small diameter can often be used to advantage to rough out the hole. In some cases, the die may be strapped to an angle plate that is inclined to the right angle; it may then be roughed out by planing or shaping with a single-pointed tool. It will be necessary to finish by filing. As a general rule, the clearance should not extend directly to the cutting edge, but only within about $\frac{1}{8}$ inch of it. Then the sides of the opening down to the beginning of the clearance should be straight, and make an angle of 90° with the bottom surface of the die. The objection to carrying the clearance clear up to the cutting edge is that any sharpening of the die will enlarge the size of the opening.

28. Hardening and Tempering the Die.—Prior to heating the die, all holes that are not intended for the cutting operation, such as the gauge-pin hole and the screw holes for the guide strips, should be plugged. Fireclay or asbestos may be used for plugging. Heat the die very slowly and evenly in a clear fire and quench it, keeping it under the quenching fluid until perfectly cold. A strong salt brine is considered by many to be the best quenching fluid, since with it the die can be hardened satisfactorily at a low heat. This brine can be made by placing in water as much ordinary salt as the water will dissolve. If the die is hardened at a low heat, experience has shown that not only is there much less danger of cracking, but also that there is a great reduction of the warping. In general it will prove advisable to harden at as low heat as possible with the grade of steel used, no matter what quenching fluid is used. Experience has shown that the hardening of steel depends primarily on the rapidity with which the heat is abstracted from it, and, to a much smaller extent, on the temperature range through which it cooled. Hence it follows that by using brine the same degree of hardness may be obtained from a lower quenching heat.

29. The die having been hardened, brighten its upper surface and temper it evenly. A good way of drawing the temper is to place a rather heavy iron plate, say, from ½ to 1 inch thick, on the fire and then place the die bottom side down on it. Move it around constantly on this hot plate, so as to avoid local heating. The color to which the die should be drawn depends largely on the nature of the material that is to be punched and on the degree of hardness that was obtained in hardening. Generally speaking, dies intended for very thin and easily severed material can be left harder than those intended for severe duty. The average color to which a die is drawn is a deep straw; however, practical experience alone can determine if this is the proper color to give in order that the die may last well.

After tempering, grind the bottom side of the die to a plane surface; a surface grinder or grinding lathe is a suitable machine. Sharpen the cutting edge by grinding the top surface and try the model in the opening. If this has closed in somewhat, bring it to the right size again by oilstoning. The die is now completed by putting in the gauge pin.

30. Fitting the Punch.—In American practice, the punch is almost invariably made after the die has been completed. The rough block is faced square and flat on its lower surface, which is then coppered. The outline of the opening in the die is now transferred to the punch block by scribing, and it is roughed out nearly to the line by milling, planing, or even by chipping and filling. The very end of the block is now carefully tapered, using the scribed outline as a guide until it will just enter into the die. The punch being made is then pressed in slightly, preferably in a press, just enough to make a distinct witness mark showing where metal is to be removed. This is repeated until the punch fits throughout its entire length. It is then faced off slightly on its lower surface in order to get rid of all traces of the original beveling, and is ready for hardening, When fitting a punch for gang dies, it is advisable to first fit the punches for the largest opening, and then the small ones.

31. Hardening and Tempering the Punch.—The hardening is usually done in brine, using a clear fire for heating. In case the punch is made in one piece, only the end is hardened; it is then drawn to the right color. As in the case of the die, experience alone can determine which is the best color; generally speaking, the punch is claimed to last better if made slightly softer than the die. Thus, if the die has been drawn to a deep straw color, the punch may be drawn to a purple or even to a blue. After drawing the temper, try the punch in the die; if it is found to have swollen in hardening, bring it to size again by grinding or oilstoning.

While directions have been given here for hardening and tempering dies, it must not be inferred that all cutting dies must be hardened. In many cases, the extra expense of hardening is not warranted, as, for instance, when only a relatively small number of punchings for soft material is required. In that case, both the die and the punch may be left soft. Judgment must be used in determining whether to harden a die or not; if the material is of such a nature that it will rapidly wear out the cutting edges, hardening may be necessary even for a small number of punchings.

32. The Shear or Dip of Dies.—When the face of a die is so formed that one part of the edge commences to cut in advance of other parts, it is said to have **shear.** The word *shear* is in very common use in the sense just employed. It is, however, used in other slightly different senses, so that in shops the term *dip* is used as a synonym.

Dies and occasionally punches may have their cutting edges so formed that the punching is cut from the stock by a *shearing* cut. The die is then said to have shear. The object of giving shear is most commonly the reduction in the force required to do the punching; in other words, it allows a press of a given capacity to punch work for which ordinarily it would not be powerful enough. Shear may be given either to the die or to the punch, or even to both.

A common way of giving shear to the die is shown in Fig. 17, which is a vertical section. In this case, the punch

is flat at its cutting end. In coming down on the stock, cutting will evidently commence at *a* and proceed toward *b* and *c* at the same time. If the punch is given a shear the reverse

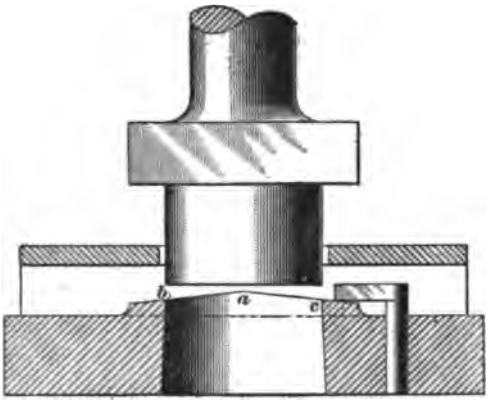


FIG. 17.

of that on the die, the shear will be doubled. Dies intended to have shear are usually made with a raised boss around the opening, as shown in the illustration. This makes them easier to sharpen.

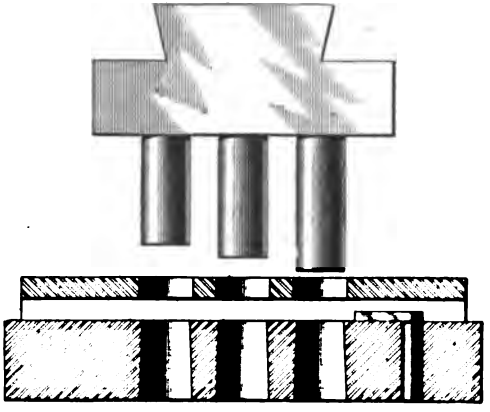


FIG. 18.

33. Sometimes the effect of shear may be obtained in other ways. Thus, referring to Fig. 18, where several holes

are to be punched in one operation, each punch may be made longer than the one next to it on the left. Then, if their difference in length is made slightly more than the thickness of the stock to be punched, the right-hand punch will have completely passed through the stock before the middle one comes down on it, thus leaving the full power of the press available for each punching blow.

34. When the effect of shear is obtained as in Fig. 18, neither the work nor the stock will be bent; if the shear is obtained as in Fig. 17, the stock that is being punched will come out bent, but the punching will remain almost flat. If the shear is given to the punch and the die is left flat, the punching will come out crooked, but the stock will be left flat. If both punch and die block are given shear, usually both the stock and the punching will come out crooked. From these considerations, the toolmaker must determine the construction for each particular case.

DIES AND DIE MAKING.

(PART 2.)

DIES AND PUNCHES.

THE DIFFERENT FORMING OPERATIONS.

1. Meaning of the Term Forming.—In a general sense, *forming* applies to all operations with dies except the cutting or punching operations. All metals when in a state susceptible to cutting operations are also more or less susceptible to forming operations of various kinds. The degree to which they are thus susceptible depends chiefly on their ductility. There is also a number of non-metallic substances on which forming operations can be performed to a greater or less degree, such as paper, cloth, leather, hard fiber, wood, etc. Some of these substances must be especially treated to prepare them for die working, as by heating, dampening, etc. The process of forming in this general sense really consists chiefly of bending the material at various points without much distortion of its area in any particular localities.

2. Forming and Bending.—Forming, in its more restricted and technical sense, usually carries the line in which the sheet is bent around in a circle or some other continuous contour. Thus, a flange or edge that is bent at a right angle, or some other lesser angle, from the general plane of a circular sheet, such as a tin-can lid, has its particles slightly disturbed in the way of compressing and stretching. This action when carried to a considerable extent, where much depth is required, comes within the

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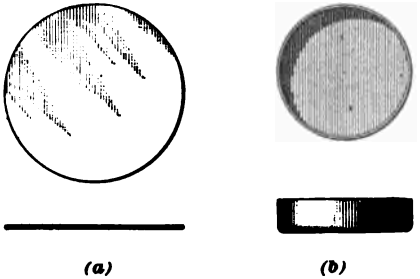
domains of the drawing process. For shallow work, where the depth is not more than about ten times the thickness of the metal, and one-tenth the diameter of the work, single-action dies can usually be employed.

Bending proper, in a technical sense, is applied to cases where the line of change from the general plane of the metal is a straight one. There is no distortion of the particles other than that due to the slight stretch on the outside and compressing on the inside along the actual corner that is bent.

3. Embossing.—Embossing is usually a process where small areas of the sheet of material are locally formed and bent so as to raise or lower them from the general plane of the sheet, as in stamping letters, pictures, and various ornamental designs. In this case there is local stretching and compressing in various spots, depending on the depth and width of the design. In many cases only the toughest metals will stand the depth of relief required to get the proper cameo or intaglio effect. In many cases ornamental designs must be toned down, so to speak, or made with less relief, to prevent the tearing of the metal in certain spots or the undue wrinkling of it in other places. Embossing differs from coining, as the sheet metal does not change its thickness, but is made hollow on one side to match every hump on the other.

DIES FOR FORMING.

4. A Simple Forming Die.—One of the simplest and most common examples of forming is illustrated in the changing of the flat circular blank, as shown in Fig. 1 (*a*), into a cup, as shown at (*b*). This can readily be done in an ordinary single-action press by the aid of **forming dies.** A single-action press is here defined as one that has but one ram.



(*a*) (*b*)

FIG. 1.

The forming dies may be constructed as shown in Fig. 2, in which a chuck is shown at *a*, which is to be bolted to the bed of the press. The die, which is shown at *b*, bored out to the outside diameter of the cup and polished on the inside, is fastened to the chuck in some convenient manner. One way of doing this is to attach it by means of a gauge ring, as shown at *c*. This ring is bored out centrally to the size of the blank, and its correct position in reference to the die is insured by fitting it to a raised cylindrical projection.

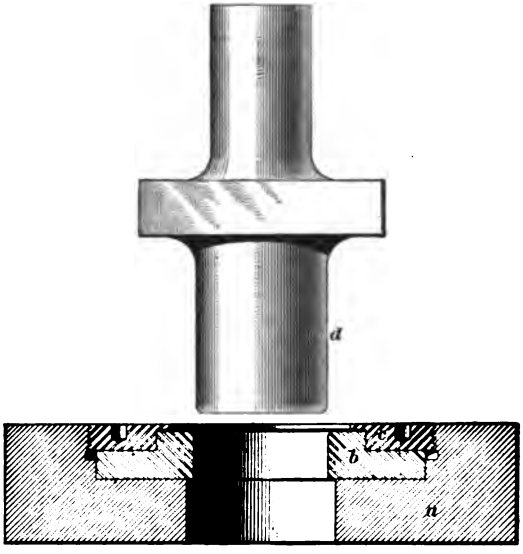


FIG. 2.

Two or more holes may be drilled near the circumference of the gauge ring, to receive the pins of a spanner wrench. The punch *d* is made equal in diameter to the inside diameter of the cup to be formed. The inside diameter of the cup equals the outside diameter less twice the thickness of the material. The blank is inserted in the gauge ring of the die, so that the punch as it descends bends up an outer zone of the blank, and in passing through the die straightens out the wrinkles that form. The punch, with the work on its

lower end, passes completely through the die. The upturned edges of the work spring slightly away from the punch, and as it ascends again, the edges catch against the sharp lower edge of the die. The work is thus stripped off the punch and falls through the opening in the bed of the press. The upper inner edge of the die must be rounded to a radius of about $\frac{1}{8}$ inch.

The die here shown performs but one operation, which is the forming of the blank into the required shape. It is sometimes known as a *plain forming die*. Such dies may also be used for forming shallow hollow articles with a flat bottom and tapering or curved sides, such as pie tins and similar work. Then the lower die is solid, but may be fitted with a spring-actuated ejector, in case the form of the work is such that it cannot readily be lifted from the die after the forming operation has been completed.

5. Forming Dies for Can Tops and Caps.—The tops of ordinary fruit cans are formed as shown at Fig. 3 (*a*).

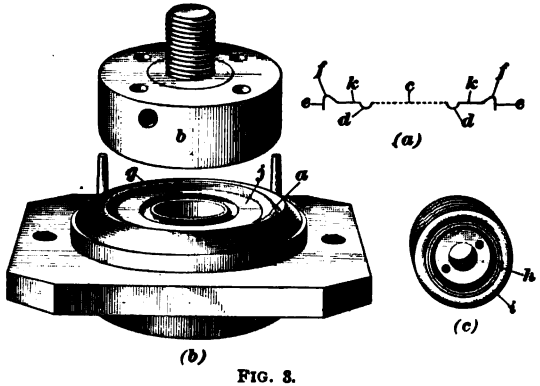


FIG. 3.

The bottoms are just like the tops, except that the hole *c* and the beading *d* are omitted, the bottoms being plain. The edges of both tops and bottoms are turned down, as shown at *e*, and a beading raised around the edge, as shown at *f*. In order to accomplish this, a *combination die*, such as shown in Fig. 3 (*b*), is frequently used. This die

may be arranged to cut either tops or bottoms. When it is desired to cut tops, a small punch for punching the holes *c* is located at the center of the large punch *b*. The small lead punch then makes the hole *c*, forcing the waste stock through the opening *g* in the die. The outer edge of the punch *b* shears or punches the outer edge of the can top or bottom, the shearing taking place between the edges of the punch *b* and the portion *a* of the die. The lower face of the punch *b* is so formed that it serves as a forming or embossing die to turn down the edges *c*, raise the ridge *f*, and form the depression *d* in the can top. The portion for forming the depression *d* is placed on the same piece that carries the punch for punching the hole *c*, and this piece is arranged to screw into the center of the die. The loose piece is shown at Fig 3. (*c*), the cutting edge that cuts out the hole *c* in the top being shown at *h*, and the ridge that draws the depression *d* being shown at *i*. The flat surface *j* corresponds to the flat surface *k* in the top When it is desired to punch can bottoms, the piece shown at Fig. 3 (*c*) is unscrewed from the punch *b*, and the center of the bottom will remain flat.

In order to form the small caps that cover the opening *c*, a punch of the form shown in Fig. 4 is frequently used. The general form of the cap is shown at *a*, and it will be noticed that its outer edges are turned down and that in the center there is a small hole to serve as a vent hole when the can is being sealed. The outer edge of the cap is cut by a punch *b*, the central portion of the die *c* being arranged on springs, so that it descends a certain distance in contact with the stock, which is held between the die and the punch, the cutting being done between the punch *b* and the die *d*, while the forming is

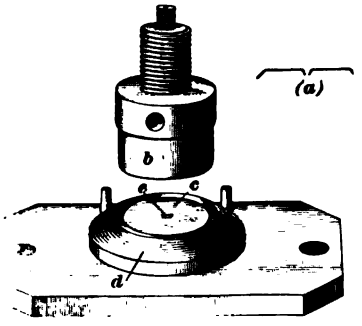


FIG. 4.

done between the punch *b* and the die *c*. The small hole at the center of the cap is formed by a small punch located at the center of *b*, which enters the hole *e*.

These two sets of punches and dies are illustrated to show some of the classes of work that can be made with this style of tool. Many pieces of metal of complicated form can be made by combination punches and dies by properly arranging the cutting and forming portions of the dies. The solution of any problem of this kind is simply an application of the principles illustrated in the different cases shown to the problem in hand, and it is possible to combine the different parts in an almost endless variety of ways.

BENDING DIES.

6. Simple Bending Dies.—A simple form of **bending die** is shown in Fig. 5. Here the upper and lower die

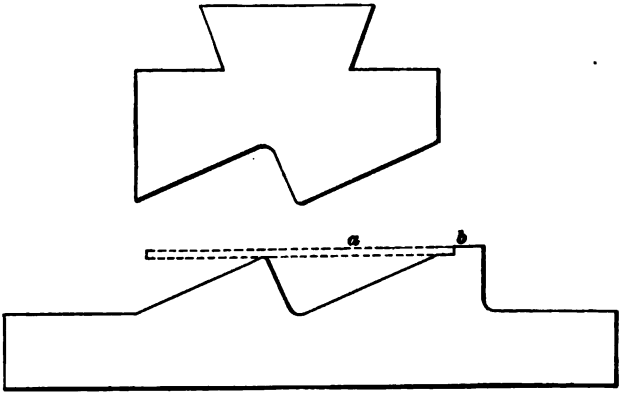


FIG. 5.

are so formed that when the upper is forced down on the blank strip of stock *a*, indicated by dotted lines, it will be bent to the required shape. In a bending die, some form of a gauge or stop is necessary in order to locate the blank properly; this must be made to suit the shape thereof, and in its simplest form may be a shoulder, as shown at *b*.

When the piece bent by bending dies, as, for instance, that shown in Fig. 6, is examined, it will be found to have a shape slightly different from that of the die. Thus, if the dotted lines represent the shape of the piece while between the faces of the dies, on removal it will assume the shape shown in the full lines, by reason of the elasticity of the material. Hence, it follows that for elastic materials the bending surfaces must be arranged to bend slightly beyond the required angle; how much beyond must be determined by experiment in each particular case. In general, the amount will be least for comparatively non-elastic materials, as annealed iron, copper, or brass, and most for more perfectly elastic metals, as spring steel, hard brass, etc. With metals like lead no allowance need be made.



FIG. 6.

When making any die for a forming operation, it is to be observed that the lower and upper die cannot have the same shape. This is shown in Fig. 7, where a comparatively thick piece of material *c* is shown between the bending surfaces of the upper die *a* and the lower die *b*. Evidently, the upper die must have on its bending surface a curve of a radius equal to that of the lower die *increased by the thickness of the material.* Due attention must be paid to this fact when making any kind of a forming die. It is also to be observed that any material will bend more easily around a curve than around a sharp corner, and at the same time there is less liability of forming a crack at the exterior surface of the bend. For this reason, the corners of the bending surfaces should be rounded off. When the substance to be bent is thin and ductile, very little rounding off is needed; the harder and

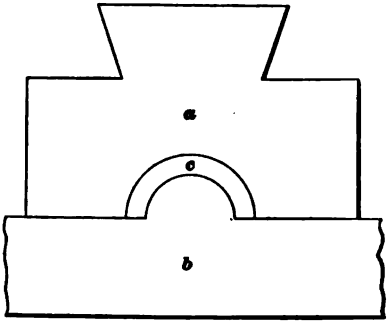


FIG. 7.

thicker the material, the more rounding must be given, in order to prevent a crack from forming in the bend.

7. Special Bulldozer Dies.—Fig. 8 shows a form of automatic die that is admirably adapted for use in a **bulldozer.** The wings w, w of the die a are folded in by the

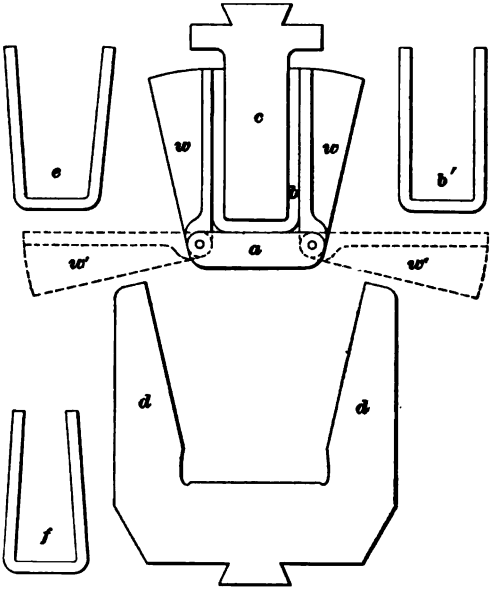


FIG. 8.

die d, thus bending the iron without stretching it. The part d acts simply as a cam to move the wings of the die. The illustration shows a piece of stock b, with the wings w, w closed about it; the dotted lines at w', w' show the position of the wings when the die is open. When working cold metal, if the punch c is made with parallel sides, as in the figure, the work will not come out parallel, as at b and b', but will be somewhat divergent, as at e, on account of the elasticity of the metal. To overcome this, the punch must be made with its edges a little convergent, so that the work when closed will have somewhat the appearance of the piece shown at f. The subsequent expanding when released will

restore it to a parallel form. The amount of this divergence depends on the kind of metal and the amount that it is heated. If entirely red hot when finished, it will act something like lead, which is practically non-elastic. As the metal is partly cooled when compressed between the cold or nearly cold dies, it may not have the exact form of the die when cold.

The machine termed a bulldozer is really a special horizontal press used chiefly for bending work. The term *automatic* as used in connection with dies is not strictly correct, but seems to be the word generally employed in dies having some of their working surfaces arranged to slide, swing, or otherwise move in relation to the other working surfaces. This form of construction is often used where a number of suboperations are performed by one motion of the press ram. Some of these motions may perhaps be at right angles to the general line of motion. The presence of spring knock-outs or ejectors would not entitle a die to be called automatic.

8. Embossing Dies.—The working surfaces of **embossing dies** must follow the design of the raised pattern to be produced. Some of them are of hardened steel and some of an alloy of lead and tin. Sometimes one is hard and the other soft-cast or hammered into it. Many degrees of hardness or accuracy may be embodied, according to the material worked, the production required, and the artistic quality of the article produced.

9. Simple Embossing Dies. One of the simplest designs of embossing die is shown in Fig. 9, where the raised outline of the work is cut into one of the dies and the other is worked out to suit the inside of the raised projection of the work. This

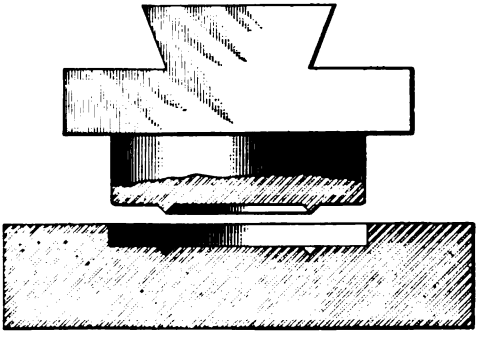


FIG. 9.

is all done by ordinary lathe work, the product being a circular bead.

Such dies may readily be made, however, to cut the blank and do the embossing in one operation, as in the combination dies already described. If this is done, the punch should not have any projections extending beyond the plane of the cutting edge. If there are such projections, they will strike the stock before the cutting edges cut the blank, and the latter, in consequence of this, will be buckled and drawn out of shape. An ejector will usually have to be fitted to a combined cutting and embossing die. This may be spring-actuated, or be positively operated by some moving part of the press, as is most convenient.

10. Seaming Dies.—Seaming dies are merely made to fit the inside and outside of a can, a bucket, or a pan, at the place where a folded-together joint occurs. They mash this joint down tighter, one die usually having a smooth face and the other a grooved face fitting the projecting seam.

A pair of such dies, for an outside seam on a can body, are shown in Fig. 10; *a* is the upper die and *b* the lower die, the latter being mounted in a horn *c* that may be inserted in a press of proper form. If the seam is to project inside the work, then the upper die must have a smooth concave face and the lower die must be grooved. A sample of the work is shown at *d*.

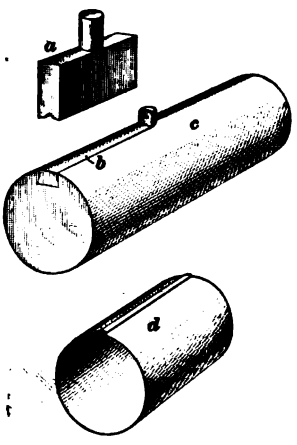


FIG. 10.

11. Curling.—The **curling** process may be defined as one in which the end of each element of a hollow object, as a cylinder or truncated cone, with walls of uniform thickness, is bent either outwards or inwards into an approximate circle, thus forming a hollow ring at the end of the object. Its general form is that of a long cylinder of

small diameter, with its axis bent around to meet itself and with a contour parallel to that of the periphery of the object to be curled. It may be either inside or outside, according to the requirements of the case. Curling differs from forming, because the metal is not simply pressed into place, but is forced to travel of itself in a predetermined path limited by the concave curve in the die that it must follow. Each element of the cylinder, or other shaped shell, must travel in this path and no other, with its end acting as a lever to start bending the oncoming portions behind. It cannot bend down with a sudden angle, thus forming a flat surface acting as a single bar, because all its neighbors are attached together to unite in resisting circumferential stresses.

12. Wiring.—The term **wiring** is often used as a synonym of curling, from the fact that curling is often performed so as to enclose a ring of wire, thus giving comparatively great stiffness to the top edge of the object so finished. This may be a tin cup, a coffee pot, a bucket, or a dish pan. Some of these utensils are cylindrical and others conical, and they may have the large end at the bottom or the top. In some cases the horizontal cross-section of the object may not even be circular, but rather elliptical, or angular with rounded corners.

13. False Wiring.—This is a name known to the tinware trade, and means wiring with the wire left out, i. e., simply curling. It is not often used, however, in describing goods. These are supposed to be wired in any case, and oftentimes are of such design as to be good enough with an empty curl.

14. Dies for Curling.—A design for **curling dies** is shown in Fig. 11, which is intended to curl a rim *a*, Fig. 12, around the open end of a piece of hollow ware. Referring to Fig. 11, the upper die *a* has a projection that fits the inside of the work, and a semicircular groove in its face at the base of the projection, as shown at *b*. The upper end of the lower die *c* is recessed to receive the rim, and the inclined surface of the recess assists in rolling it inwards. This is

shown to a larger scale in Fig. 12, where the rim is fully formed. The diameter of the curl, or rim, that can be produced is rarely over $\frac{3}{16}$ inch for a good quality of tin

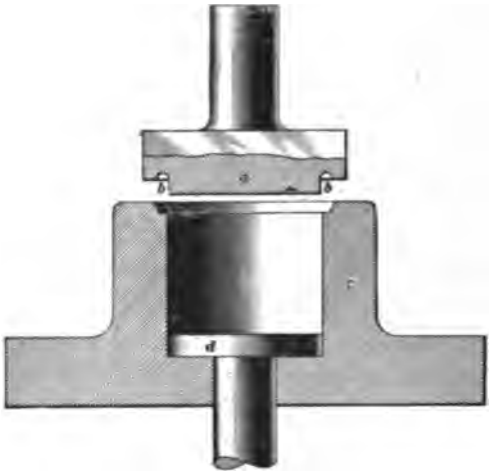


FIG. 11.

plate; if a larger rim is produced, the metal will have to stretch so much that it will tear. If it is well annealed and has not been hardened by any previous drawing, forming, or embossing operation, a much larger rim can sometimes be curled. When the work is of such shape that it cannot readily be removed with the fingers from the lower die, an ejector, as *d*, Fig. 11, may be used to advantage. The same die may also be used for curling the edge of the work over a wire ring.

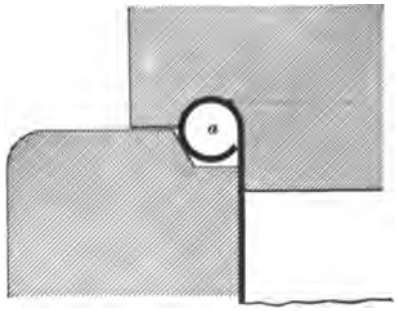


FIG. 12.

15. Tapering Curling Dies.—Tapering curling dies are shown in Fig. 13, arranged for wiring the top of a rather deep dish pan. The lower die (*a*) is simply a cast-iron

container fitting the outside of the pan, grooves being provided at *c* and *d* for the outwardly projecting seams—it being a case of pieced ware, rather than a drawn pan. The upper die, shown at (*b*), is upside down and is usually made of an iron body *e* with a steel ring *f* (secured to it by screws) to form the grooved working surface that does the curling. In this case the working ring is divided into several sections by narrow radial slits, that it may be collapsible and thus may crawl into a smaller diameter, as it descends into the decreasing conical pan. For conical work that is smallest at the top, like coffee pots, etc., this action is reversed, and the slit

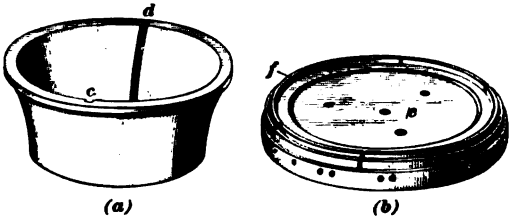


FIG. 13.

ring expands as it goes down. It of course starts with the sections in contact in this latter case. In both cases, the return of the ring to its normal size is performed by a number of spiral springs set radially in the plate of the die. For parallel-sided work, the curling ring can obviously be solid, as it need not change its diameter. This is shown in Fig. 11, the work being in the nature of a tin cup or a dinner pail.

Where curled work is of much depth, the lower die is usually made to swing or slide forwards for inserting and removing the work, thus avoiding the necessity of a very long stroke in the press ram.

THE DRAWING PROCESS.

16. Drawing.—In a certain sense, **drawing** is an extension of the forming process. It differs from it chiefly in the fact that an outer zone of the flat blank that is required to be formed into a hollow shape is confined between two rigid flat surfaces in such a manner that, as it is drawn radially inwards from between them, no wrinkles can form.

The products are a variety of cup-like forms of cylindrical, conical, and approximately hemispherical shapes. Sometimes these have at the open end a flat, outwardly projecting flange; then the general shape may be termed hat-like.

17. Object of Drawing.—When an attempt is made to form a rather deep article from a blank in forming dies, the edges of the blank commence to wrinkle, and in extreme cases will even fold up so that the folds will lie over each other. These folds, as the wrinkles may be called, are well shown in Fig. 14, which is an illustration of a tin-can cover that has been produced by forming dies. Inspecting it closely, it will be seen that, for a short distance above the bottom, the sides of the rim are smooth. Farther up the wrinkles commence to form, and gradually become larger toward the upper edge. It is not known who first discovered that if an annular zone of the blank is confined between two flat surfaces strongly pressed together by springs or other means, and that if the metal is then drawn out from between them, no wrinkles will be formed. The piece pressed down on the blank, holding it in place, is called the **blank holder.** This discovery is of comparatively recent origin, but has proved of a far-reaching influence in the cheap production of many articles, especially household goods, such as pots, kettles, dippers, and pans.



FIG. 14.

18. Redrawing.—The process of **redrawing** is an extension of the drawing process; in other words, it is simply the drawing process repeated in order to deepen the hollow shape formed by drawing. In the redrawing, the diameter is reduced at the same time that the length is increased. Sometimes this redrawing is repeated several times, perhaps a dozen or more. The work then assumes more the appearance of a tube than a cup, one end of course being closed. Both drawing and redrawing dies having a blank holder to prevent wrinkles are known as **double-action dies.** The

special motion of the blank holder may in certain cases be obtained by springs in a single-action press. In most cases, however, a double-action press must be used, having a special motion, followed by a *dwell*, that is, a pause, for the ram, while the plunger inside the ram continues its stroke.

DRAWING DIES.

19. The Spring Drawing Dies. — The **spring drawing dies** shown in Fig. 15 are intended to draw the

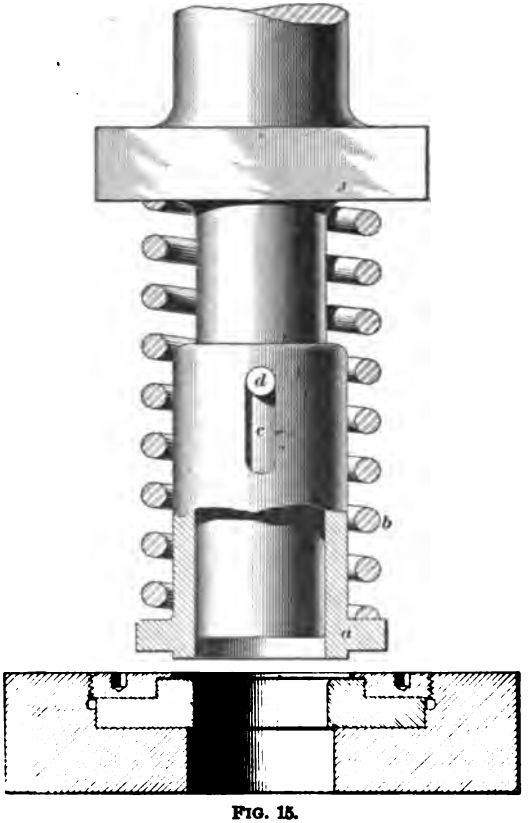


FIG. 15.

same piece that was illustrated in Fig. 1 (*b*). Referring to Fig. 2, it is seen that the lower dies are identical. The

upper die, or punch, is surrounded by the blank holder *a*, which is held to its lowest position by a powerful helical spring *b*. The punch is free to slide through the blank holder, when the latter comes to rest by reason of coming in contact with the blank lying in the gauge ring; to allow this to occur, the stem of the blank holder is slotted, as shown at *c*, where a cylindrical pin *d* in the side of the punch forms a stop for the blank holder. As the punch descends, the blank holder strikes and the spring is compressed before the punch strikes the blank; as it continues to descend, the annular zone confined between the lower surface of the blank holder and the upper surface of the die is gradually drawn radially inwards, and, passing over the rounded upper edge of the die, is formed into a rim without any wrinkles. Obviously, the metal is compressed, or *upset*, circumferentially, while being stretched radially, its thickness remaining about the same.

The work appears in different stages in Fig. 16, where (*a*) shows a cross-section of the blank, (*b*) shows the cross-section when the punch has partially entered the die, and (*c*) shows the work when the punch is fully in the die. The work is stripped off the punch, as it moves up, by the sharp lower edge of the die.

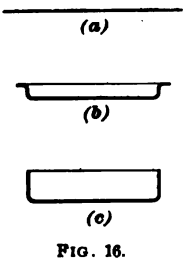


FIG. 16.

If the rim formed by the drawing operation shows wrinkles, it indicates that the pressure with which the outer zone of the blank was held was insufficient. The remedy is to stiffen the spring or substitute a heavier one. On the other hand, if the punch tears through the blank, the spring is too stiff, and must either be eased or a weaker one made.

It is essential to successful drawing that the working parts of the die be highly polished, and that the material to be drawn be soft. The depth to which a cup can be drawn in one operation depends on the ductility of the material; with well-annealed copper, a depth equal to two-thirds the diameter is often obtained. Experiment alone can determine for each particular case what depth can be attained by one drawing

operation. The depth relatively to the diameter depends much on the thickness, as well as the quality, of the material.

20. Combination Cutting-Drawing Dies on Plain Work.—It is obvious that for making a cup as shown, two

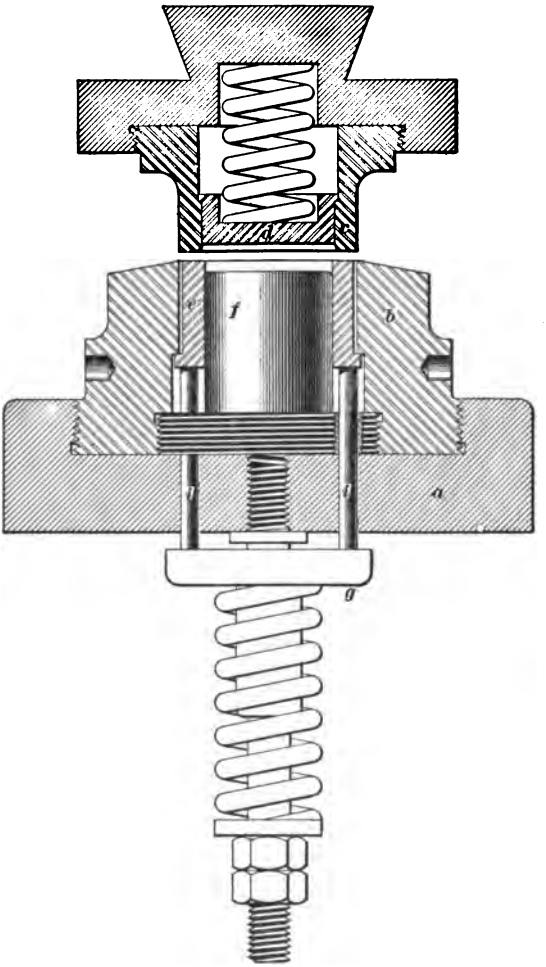


FIG. 17.

separate operations must be performed, namely, *cutting* and *drawing*. When a large number of pieces are to be drawn,

however, dies may be designed that will cut the blank and form the cup in one operation, thus greatly reducing the time cost per piece. Such dies will be about twice as expensive as two single pairs of dies.

A variety of combination **spring drawing dies** is shown in Fig. 17, which is intended to draw the same piece that was shown in Fig. 1 (*b*). Referring to Fig. 17, *a* is a lower chuck holding the die *b*, which is bored to the diameter of the blank, with its upper edge sharp. The blank is cut out by the punch *c*, the outer edge of which is also sharpened to form a cutting edge. The punch is bored centrally to the outside diameter of the cup, and the inner edge is nicely rounded. An ejector *d*, actuated by the helical spring shown, serves to push the cup from the upper die in case it should stick there. This is free to move in the direction of its axis, and is confined as to its lowest position by a shoulder in the cutting punch and an abutting flange of its own.

The blank holder *e* is placed within the lower die; it surrounds the forming punch *f*, which is stationary in this case. The blank holder also serves to strip the finished cup from the punch. The pressure on the blank holder is obtained from a helical spring placed below the chuck; this spring operates on a movable sleeve *g* with a large flange in which pins *i*, *i* are carried. These pins pass freely through holes in the chuck and the flange of the punch; they abut against the lower surface of the blank holder, which is thus actuated by the spring. The lower die must be provided with a suitable guide strip, gauge pin, and stripper for the stock, arranged in the same manner as for any ordinary cutting die. These appurtenances have been omitted in the drawing for the sake of clearness.

21. The Operation of Cutting-Drawing Dies.— The operation of these dies is as follows: The descending upper die cuts the blank from the stock; it is immediately gripped by the blank holder and confined between its upper surface and the lower surface of the cutting punch, the spring below the bolster giving the pressure necessary to

prevent wrinkling during the drawing. As the upper die keeps on descending, the blank and blank holder are carried down until they strike the upper surface of the forming punch *f*; the outer zone of the blank is then gradually pulled out and the cup is formed around the punch. The appearance of the work in successive stages is the same as was shown in Fig. 16, except that the work will be bottom side up.

In order that the blank holder may be inserted, the lower die and forming punch must be made separate. They may then be connected together in any convenient way that will insure proper centering, as, for instance, by providing the punch with a threaded flange screwed into a threaded recess of the die, as shown. All spring-drawing dies are intended to be used in *single-action presses*, although they are double-action dies.

22. When a *double-action press* is available, a very much simpler design of drawing dies is possible. Such a press is provided with two rams working within each other, and independently adjustable. The outer ram, conveniently termed simply the *ram*, is so actuated that for a certain period of the revolution of the press shaft it will be at rest. The inner ram may properly be termed the *plunger*. It continues its downward motion, giving a certain excess travel, by which is measured the attainable depth of work. Fig. 18 shows a design of drawing dies for a double-action press, intended to form the cup shown in Fig. 1 (*b*). Referring to the illustration, *a* is a chuck bored to receive the drawing die *b*, and threaded to receive the cutting die *c*. To insure correct location of the two dies with reference to each other, the one may be recessed to fit a central projecting shoulder of the other, as shown. The two dies may be rigidly held together by any convenient means; for instance, the outside of the cutting die may be threaded, and suitable holes may be provided to receive a wrench, as shown in the illustration.

The upper die *d*, which is the blank holder and at the same time the cutting punch for the blank, is fitted to the

ram, and the inner part, or drawing punch *e*, is fitted to the plunger. The ram is so adjusted that when *d* has descended and is at rest, it is close enough to hug the blank confined between its lower surface and the upper surface of the die, and thus furnish the pressure necessary to prevent wrinkling. The drawing punch is to be so timed that it will not strike the blank until it has been confined by the blank

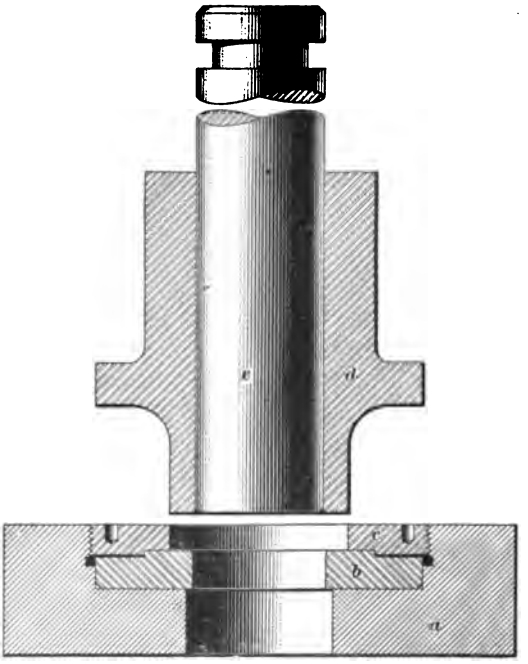


FIG. 18.

holder. The cup is then drawn by the punch. The finished cup is stripped off by the sharp lower edge of the drawing die. This kind of a die is comparatively inexpensive; the price should not exceed 50 per cent. more than plain drawing dies that do not cut; it should be considerably less than that of cutting-drawing dies for a single-action press, where spring action must be provided.

23. Drawing Work With Tapering or Curved Walls.—So far, only the drawing of cups with walls at a right angle to a flat surface has been considered. It is possible to draw work with tapering or curved walls, however, as, for instance, the work shown in cross-section between the upper and lower dies of Fig. 19. In this case, a flange

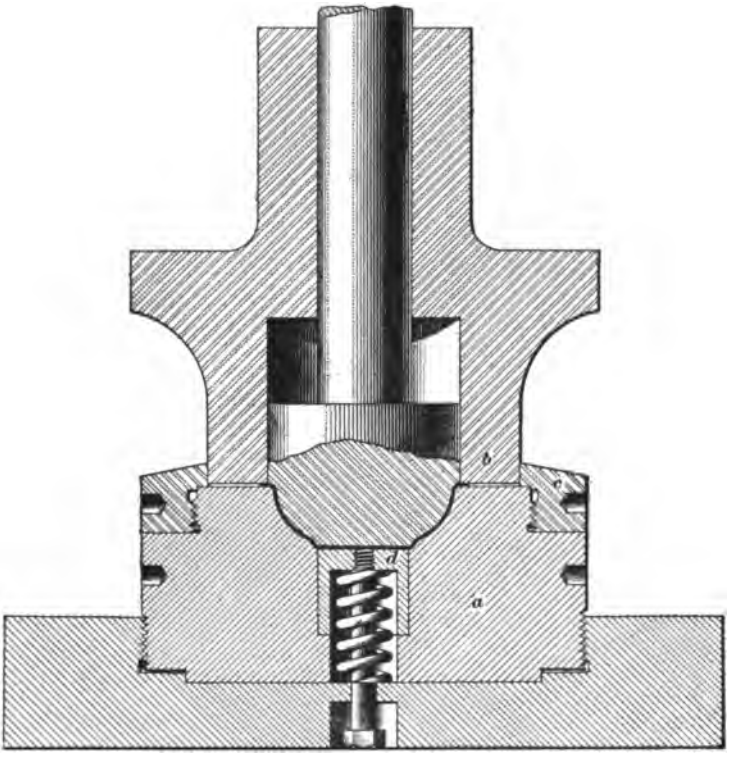


FIG. 19.

is left on the open end of the work, which is done by not drawing the metal entirely from between the blank holder *b* and the upper surface of the drawing die *a*. The die shown is a combined cutting and drawing die; the cutting edge of the lower die is formed on a removable ring *c*, and hence is easily renewable in case of wear or accident. To eject the

drawn work from the lower die, an ejector *d* may be fitted. This may be spring-actuated, as shown, or it may be positively operated by some moving part of the press. Whether or not an ejector, often known as a *knock-out*, is to be fitted depends on the shape of the work. In many cases this is such that it can easily be lifted out of the lower die; in that case, the ejector may be omitted. Drawing dies for work as shown need not always be made of tool steel. In many cases they may be made advantageously of close-grained cast-iron.

The particular design of dies shown in Fig. 19 is intended for a double-action press. It is also possible to design combination dies for the same work to use in a single-action press. Such may be constructed on the same principles as the die shown in Fig. 17.

In order to prevent wrinkles from forming in the walls of work having a cross-section similar to that shown in Fig. 19, the pressure of the blank holder on the confined outer zone of the blank must be quite heavy. If wrinkles cannot be prevented from forming in the body, they can afterwards be removed by roller-spinning the work in a suitable lathe.

24. Combined Cutting, Drawing, and Embossing Die.—For work like that shown in Fig. 20 (*a*), dies may be designed that will cut the blank, draw the rim, and emboss the flat top in one operation, thus enormously reducing the time cost per piece below what it would be in case these three operations were performed in separate dies. The design of die to be used for this class of work depends on the type of press that is available.

For a single-action press, the design shown in Fig. 20 (*b*) is a satisfactory one. As a matter of course, this may be modified in various ways to suit conditions. In the illustration, the dies are shown hard together, with the work between them; when the dies are apart, the upper ejector *a* projects beyond the face of the embossing punch *b*. The combined blank holder and ejector *c* in the lower die is then

in its uppermost position. The pressure necessary for successful drawing is supplied by a number of heavy helical springs that may extend into recesses bored into the blank holder in order to effect a saving in the height of the die. For the same reason, the springs for the upper ejector may

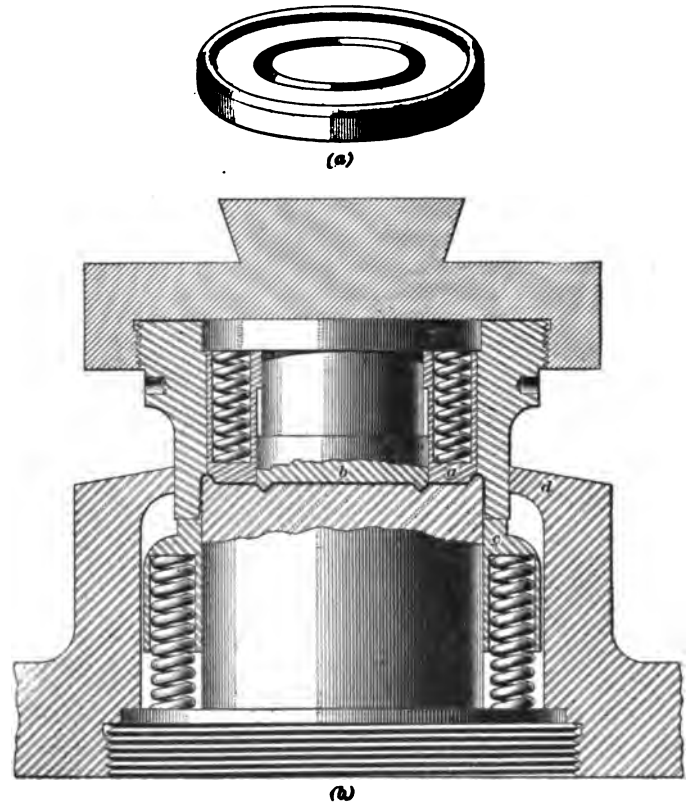


FIG. 20.

be placed within recesses bored into it, if circumstances permit. The lower cutting die may be solid, as shown, or a small tool-steel ring may be attached to a cast-iron body. The point to be observed in making any kind of a combination die is to design it so that it is cheap in first cost, and that all wearing parts can be easily and cheaply renewed.

When a double-action press is available, these dies may be designed as shown in Fig. 21. Evidently no stripper will be needed for the upper die, as the embossing and drawing

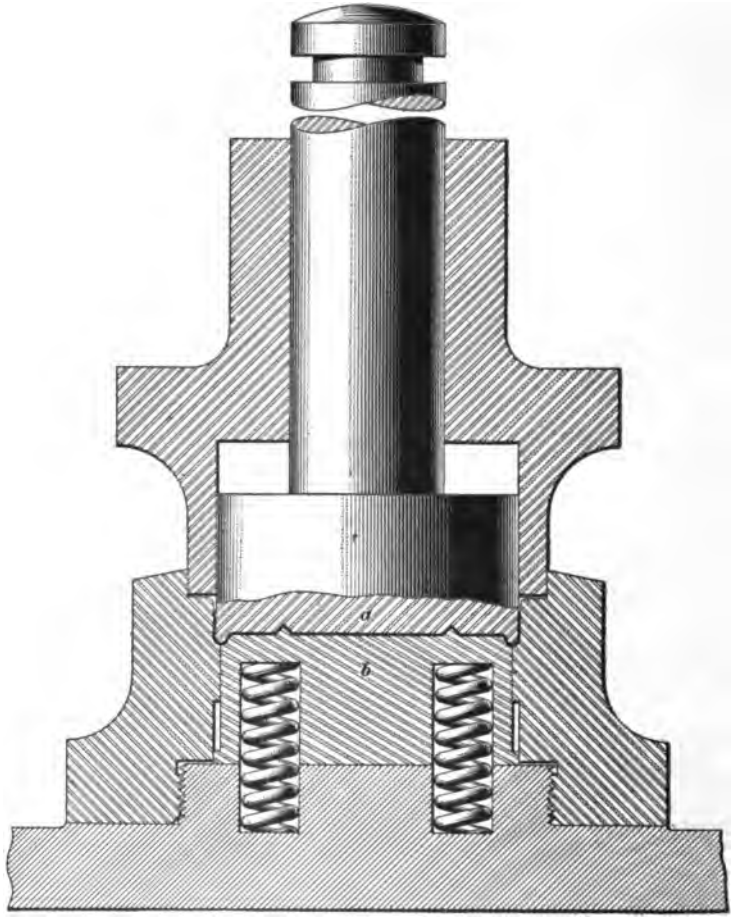


FIG. 21.

punch *a* will automatically strip the finished work from the upper die. The lower embossing die *b* may act as an ejector by making it movable. It is then actuated by the spring shown. If it is stationary, then an ejector may rise inside

of it. Comparing Figs. 20 and 21, it is seen that there is far less work required to make the dies for a double-action press. The design shown may be modified in various ways, as deemed advisable by the toolmaker. Referring again to Figs. 20 and 21, the lower die should be fitted with a suitable guide strip, gauge pin, and stripper for the stock. These have been omitted in the drawing for the sake of clearness.

25. Triple-Action Drawing Dies. — Both of the designs just shown will discharge the finished work on top of the lower die. In many cases this is objectionable; the

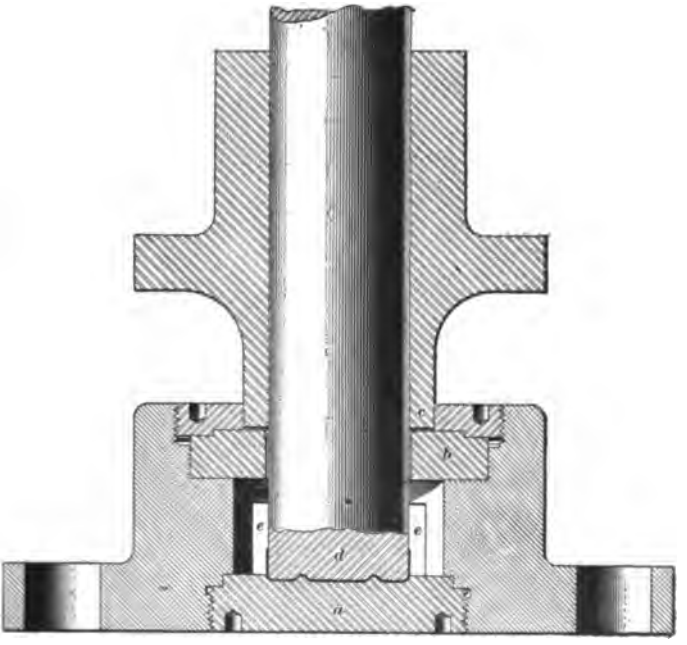


FIG. 22.

design may then be modified, as shown in Fig. 22, if circumstances permit. In this case, the lower embossing die *a* is entirely separate from the drawing die *b*, and is placed some distance below it. The blank holder *c* cuts the blank and holds it; the drawing and embossing punch *d* first draws the

rim of the work and finally embosses the bottom. As the punch ascends, the sharp lower edge of the drawing die strips the work off from it. The work then falls and is removed through the opening *e* in the lower die. It will rarely be necessary to fit an ejector to the embossing die. Evidently, this design of die can be adopted only for the work that can be pushed laterally clear through the drawing die.

These dies are of the general class known as **triple-action,** because originally the lower embossing die was operated from below by a separate special ram, thus making three motions to the press instead of two. The present practice, however, is usually as shown.

Obviously, the stroke of the press plunger must, relatively to the ram stroke, be longer than usual.

26. Discharge of Work From Dies.—The lateral ejection of the work, through the doorway *e e*, Fig. 22, at the back of the die, is sometimes performed by a sliding pusher rod worked by the press. More often, however, the press is set in an inclined position of some 40° from the vertical, so that work done in these dies, and also in such as are shown in Figs. 3, 4, 17, 19, 20, 21, and 22, may slide out by the action of gravity.

SIZE OF BLANKS FOR DRAWING AND FORMING.

27. Obtaining the Size of the Blank by Trial. The only sure method of getting the correct size or shape of a very irregular blank that is to be subjected to a drawing or forming operation is a tentative one. Naturally, it is likely to prove expensive. A blank is cut as near to the correct size as judgment dictates; it is then drawn or formed and the results are observed. A new blank is then prepared, modified from the first one in accordance with the results obtained in the first trial. This is then drawn or formed, and the cycle of operations repeated until the correct size and shape of blank are obtained. The cutting parts of combination dies are often left unfinished while the drawing

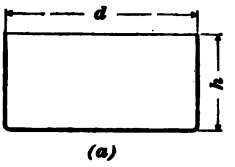
parts are used to ascertain the cut in the manner just explained.

28. Rules for Size of Blank.— The following formula for the diameter of the blank in cylindrical work will give quite a close approximation to its correct size:

Let d = diameter of cylindrical cup in inches;
h = height of cup in inches;
r = radius of corner in inches;
x = diameter of circular blank in inches.

Then, for a sharp-cornered cup, as shown in Fig. 23 (*a*),

$$x = \sqrt{d^2 + 4dh}. \qquad (1.)$$

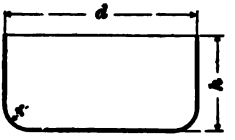


(*a*)

EXAMPLE.—Find a trial diameter of blank for a cup to be drawn 1 inch deep and 2 inches in diameter.

SOLUTION.—Applying formula **1**, and substituting values, we get

$$x = \sqrt{2^2 + 4 \times 2 \times 1} = 3.464 \text{ in.} \quad \text{Ans.}$$



(*b*)
FIG. 23.

29. For a round-cornered cup, as shown in cross-section in Fig. 23 (*b*),

$$x = \sqrt{d^2 + 4dh} - r, \qquad (2.)$$

provided the radius of the corner is not more than $\frac{1}{4}$ the height of the cup.

EXAMPLE.—Find a trial diameter of blank for a cup having a radius of $\frac{1}{4}$ inch to the round corner, when the height of the cup is 1 inch and its diameter is 2 inches.

SOLUTION.—Applying formula **2**, and substituting the values, we get

$$x = \sqrt{2^2 + 4 \times 2 \times 1} - \tfrac{1}{4} = 3.214 \text{ in.} \quad \text{Ans.}$$

30. For drawn or formed work that is not cylindrical, but circular in plan view, as, for instance, that shown in Fig. 24, the following method may be used for obtaining the trial diameter of the blank.

Make a full-size drawing of the profile that is to be formed, as in Fig. 24. Commencing at the intersection of the axis with the profile, and to one side of the axis, step off divisions $\frac{1}{8}$ inch long, as *1*, *2*, *3*, *4*, etc. From the center of each

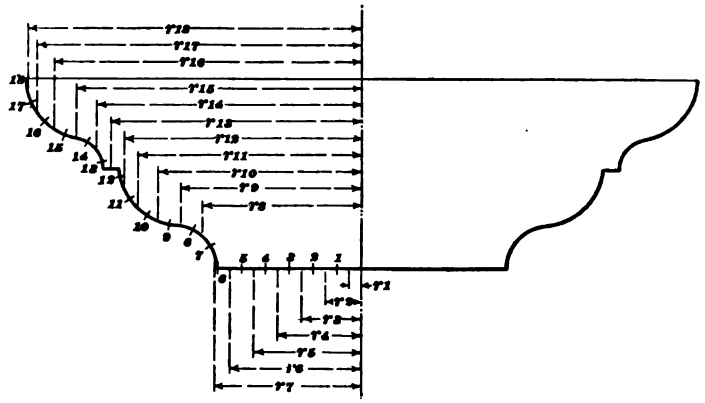


FIG. 24.

division thus stepped off measure the perpendicular distance, as r_1, r_2, r_3, r_4, etc., to the axis in inches. Add the distance and extract the square root of their sum to obtain the approximate diameter of the blank.

EXAMPLE.—Assuming that Fig. 24 is a full-size profile of the work, what would be the trial diameter of the blank?

SOLUTION.—Measuring the distance with a decimal scale, they are found to measure .06, .19, .31, .44, .56, .69, .75, .84, .95, 1.06, 1.17, 1.24, 1.31, 1.38, 1.48, 1.61, 1.70, 1.74 in. Their sum is 17.41 in., and the square root of this number is 4.18, which is the approximate diameter of the blank in inches. Ans.

REDRAWING DIES.

31. Simple Redrawing.—Redrawing dies do not differ essentially from ordinary first-operation drawing dies, and may be designed in the same manner for a single-action or a double-action press. The gauge ring is to be made to the external diameter of the cup, and the blank holder to the inside diameter. The appearance of the cup in successive

stages of the drawing and redrawing process is shown in Fig. 25. At (*a*) the blank is shown, which is formed into the cup shown at (*b*) by plain drawing dies or combined cutting and drawing dies. The cup, after annealing, is placed into the gauge ring of the redrawing dies, and the punch in descending pulls the metal from between the blank holder and the upper surface of the drawing die, first into the shape shown at (*c*), and finally into that of an elongated cup shown at (*d*). This cup, after annealing, may be redrawn again, its appearance when partially redrawn being shown at (*e*) and when fully redrawn, at (*f*). The greatest amount that the diameter of a cup can be reduced in each drawing operation is usually placed at two fifths of the diameter. Thus, a cup 2 inches in diameter may in one drawing be reduced to $2 - 2 \times \frac{2}{5} = 1\frac{1}{5}$ inches. Experiment alone will determine positively for each particular case if this reduction of diameter can be obtained. The amount depends on the character of the metal and the thickness of the sheet. In Fig. 26 is shown, in a vertical section, a pair of double-action redrawing dies in their simplest form, *a* being the blank holder and *b* the punch. These are suitable for drawing (*d*) into (*f*), as shown in Fig. 25.

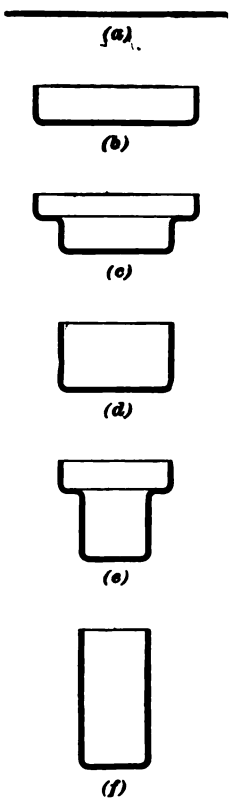


FIG. 25.

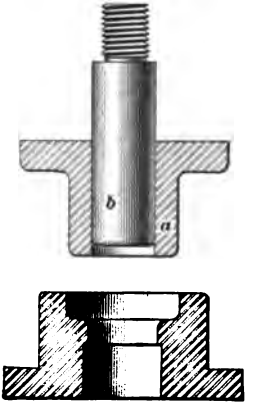


FIG. 26.

32. Reverse Redrawing.—For some work, a process known as **reverse redrawing** may be used advantageously. Fig. 27 shows dies for reverse redrawing designed for a double-action press. The figure shows between the punch and die, a cup that is partially redrawn; it will be observed that this cup is being redrawn in a direction the reverse from that in which it was drawn. In the illustration, *a* is the punch, *b* the blank holder bored to fit the outside of the cup, and *c* is the die, the outside of which is turned and polished to fit nicely the inside of the cup. Shapes that may be

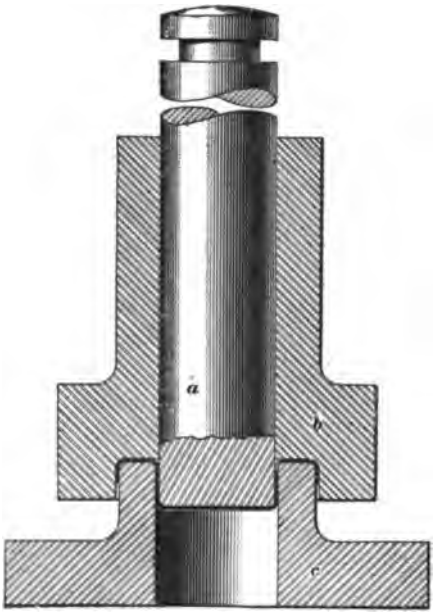


FIG. 27.

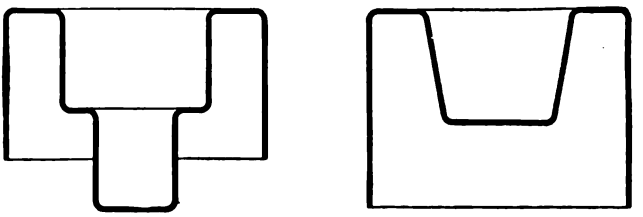


FIG. 28.

redrawn by reverse redrawing are shown in Fig. 28; these will serve to suggest others.

In Fig. 29 are shown in vertical section five stages of drawing a deep cup *a*. The piece at the end of the first operation is shown at *b* and *c*; *d* and *e* show successive

operations. The finished cup is shown at *a*. The fifth operation, being a small reduction, is performed by single-action redrawing dies.

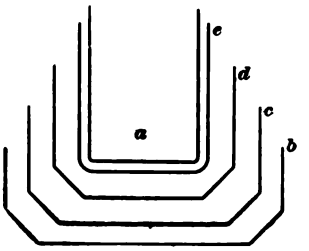


FIG. 29.

In Fig. 30 (*a*) is shown a simple form of single-action redrawing dies, such as would be suitable for drawing the cup shown in Fig. 29 from the form shown at *e* to that at *a*.

In Fig. 30 (*b*) is shown a typical single-action redrawing die at *a*, a punch at *b*, and a cartridge shell at *c*. Here both drawing and **broaching** have been performed. The latter consists of squeezing thinner the walls of the shell, by making the space between punch and die too small for the metal. In this case the punch is conical and the walls of the shell thinner at the top end. Even if parallel, they can be made thinner than the original metal at the bottom of the cup if desired.

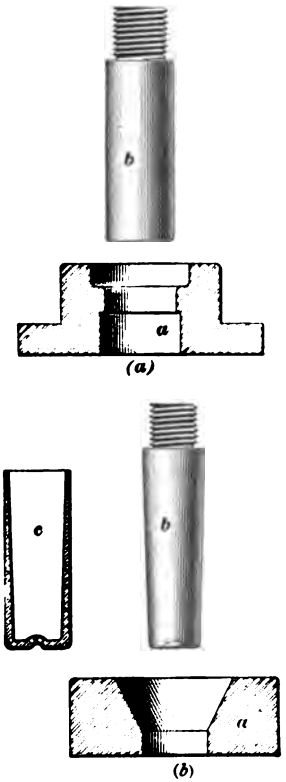


FIG. 30.

COINING PROCESSES.

33. Application of the Coining Process.—The process of **coining** consists in so pressing or mashing the material that its particles start to flow in any or all directions, following the lines of least resistance. Obviously, brittle materials cannot be treated in this way to much extent, although some substances apparently non-ductile flow in a remarkable way. Instances of

this are shown in the action of glaciers, where the solid ice flows down through valleys at a very slow rate, entirely changing its shape through years or centuries of action, without crumbling, but, on the other hand, acting after the manner of a liquid of great viscosity.

Another instance of such action is seen in a cake of pitch, through which stones will gradually sink by their own weight, at a very slow rate of motion, the pitch closing over them intact, as if it were a jelly-like material.

Under ordinary circumstances, however, such substances as hardened steel, cast iron, pitch, chalk, or ice, commonly supposed to be brittle, do crumble when subjected to pressure beyond their elastic limit. The ductile metals and some other substances, such as clay, wax, butter, etc., are legitimate subjects of the coining process. Such ductile metals as steel, iron, copper, etc. will flow farther and under very much less pressure if heated red hot than if cold. Hence, all the ordinary operations of forging, from the rolling mill and steam hammer down to the country blacksmith shop, are performed with the metal heated to redness. In the coining process as applied to practical arts, these flowing materials are usually confined in dies or molds of some kind to bring them to the desired shape. The products of such molds are very familiar to the public when in the shape of cakes of soap or pats of butter; but exactly the same principles are applied in the coining of money, which concerns certain metals, such as gold, silver, bronze, nickel, aluminum, etc.

In that process of the art, which is technically called coining, the products of which are usually coins of the realm, medals, or badges of various sorts, the metal is worked cold. The two impressions on the obverse and reverse sides of the coin are made by dies engraved with the proper design, working in a so-called collar. The collar confines the metal from spreading too far edgewise and serves as a mold for the edges. These may be smooth, as in American cents, or *reeded* with small grooves, as in American silver coins of various sizes. In order to give a thickened rim, and to insure

the rounded corners that are desirable for beauty and for smoothness, the disk of metal from which a coin is to be made is *milled* on the edges. This process consists in rolling the coin between grooved jaws so as to form a thickened and well-rounded rim. In this form it is called a **planchet.** The pressure of the dies causes the metal to flow into and fill all the spaces that form the inscriptions and ornamental or emblematical designs, and also to force the metal out sidewise to fill the collar and form any reeding or lettering that may be cut on the rim. Were the pressure too great, the metal would flow up into the small apertures between the dies and collar, forming a thin fin projecting at right angles to the face of the coin. The action of the dies must therefore be limited, so as to stop before this thin fin commences to form.

34. Coining Dies.—In Fig. 31 is shown at (*a*), in vertical section, a pair of **coining dies,** the collar surrounding

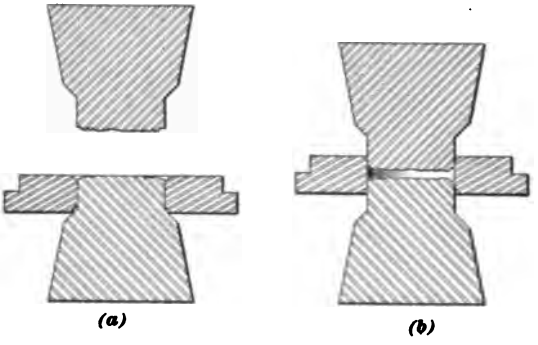


FIG. 31.

the lower die being in its natural position at the time when the upper die has risen out of the way, and the lower die has risen enough into the collar to eject the finished coin and allow it to be taken off by the fingers in case of hand feeding, or swept off by the next incoming planchet if the press happens to be automatic. At (*b*) is shown the same

dies when in closed position at the time the impression is being made. Obviously, the space between them and between the sides of the collar represents the exact size and shape of the coin, with the exception of the rounded corners previously referred to.

Such dies may be made for coins of other than circular contour, as elliptical, octagonal, etc.

35. Drop Forgings.—When a number of forgings of the same pattern are to be made, the work is often done by driving or pressing the metal into a lower die by the action of a flat-faced die set in the ram of a drop hammer. The metal is usually red or white hot, especially if it is iron or steel. This process is called **drop forging,** although sometimes the products are made by so-called forging presses with a number of blows from a positively driven short-stroked ram, rather than by the fall of a heavy ram with a long stroke. It is frequently shaped by several sets of dies before it has acquired the desired form, or the work is roughly formed by hand and then finished in the dies.

36. Dies for Drop Forging.—Fig. 32 (*a*) shows a set of dies that may be used in drop forging the wrench shown in Fig. 32 (*b*). The end of a bar of iron is upset to gain stock for the head of the wrench; this may be done by hand or in a machine. The bar is then put into the first die *a*, which acts like a fuller and spreads the iron at the point out toward the edges. The handle is partly formed in this die. The partly finished piece, which is shown at *f*, is then put into the second die *b*, and the handle finished and the metal in the head pressed well into the die. When the forging is taken from this die it has the form *g* of the finished wrench, but the fin of metal *h* that squeezed out of the die is still attached to it. This fin is sheared off by the trimming die *c*, which is really a punch, the portion *d* fitting into the die *c* for this purpose. The end *k* is left on and serves as a handle for the wrench during the operation. It runs out into the bar of greater length than shown. When

trimmed, the wrench r falls into the pocket in the bottom of the die and is pulled out through the slot s. The end k

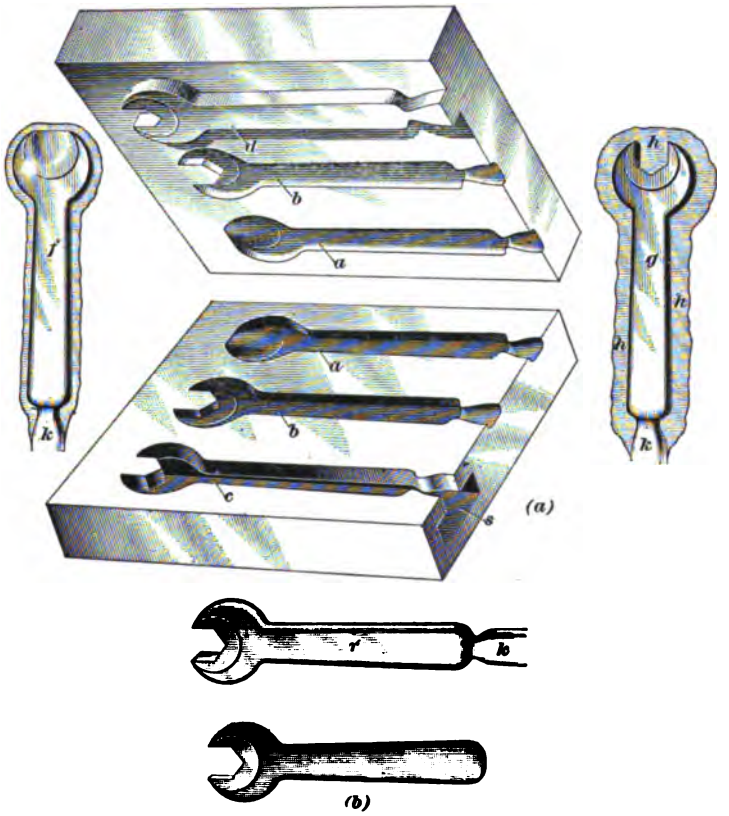


FIG. 32.

is finally cut off on a shear, and the edges finished to the form shown in Fig. 32 (b) by grinding on an emery wheel.

37. Tube Squirting.—A process analogous to coining, and involving the same principle of the cold flow of metals, is the pressing of small disks of soft metal, such as lead, tin, and various alloys, into the thin cylindrical tubes

used for holding paints, toilet pastes, etc. In Fig. 33 (*a*) is shown a pair of dies for this purpose, which, it will be noticed, are very simple. At (*b*) is shown a disk of metal, punched out in another machine, and at (*c*) is shown the tube after the pressure has caused the metal to follow the shape of the lower die, including the hole in the center and the threaded neck. The pressure of the punch causes the surplus metal to flow up the sides of the punch in the form of a thin shell, the length being determined by the amount of squeezing that is performed after it commences to crowd upwards. Where the work has a thread coined on it, it must be removed from the die by rotation to unscrew it.

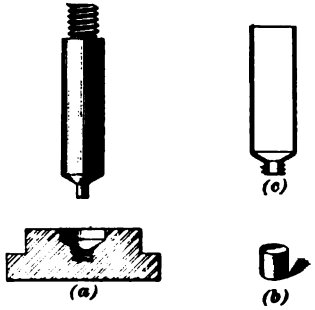


FIG. 33.

If the lower die has simply a cylindrical recess and the punch a plain solid cylinder, the tube would of course be a plain shell with a flat bottom, the thickness of the latter depending on the distance the punch descended, and the thickness of the walls depending on the amount of space at each side between the punch and the die. In such case the blank (*b*) might be of thinner metal than shown and of larger diameter, as, for example, the diameter of the outside of the tube.

JIGS AND JIG MAKING.

JIGS.

CLASSES AND USE OF JIGS.

DEFINITIONS.

1. In the manufacture of duplicate parts, special devices or fixtures are largely used for guiding the cutting tools in such a manner that the work produced by them becomes alike in all essential features, independent of the skill of the operator. Such devices or fixtures are commonly called **jigs**; they are used chiefly for the production of holes of circular cross-section by drilling or reaming operations or by both in conjunction, and are also used occasionally for guiding taps, files, or other tools.

2. Jigs are called **drill jigs, reaming jigs, tapping jigs,** or **filing jigs,** or, in case of several operations of different kinds, **combination jigs**; the name given implies the operation in the performance of which the jig is intended to aid. The design of jigs for any of these operations does not differ in any essential particular; hence, whenever the word "jig" is used hereafter, it will be understood to be applied in the general sense.

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ESSENTIAL PARTS.

3. All jigs consist of certain essential parts, which are: the **guides** for the cutting tools; the **body,** which supports the guides and the work; the **stops,** or **gauges,** which locate the work correctly in reference to the guides and to one or more points or surfaces of the work; the **clamping arrangement,** which serves to hold the work to the body; and the **supporting surface** or surfaces, which rest on the table of the drill press and insure parallelism of the axes of the guides with the axis of the spindle that carries the cutting tool.

4. The clamping arrangement and the supporting surface do not necessarily form an integral part of the jig, but may be separate therefrom. Thus, in some cases, the jig and the work may be held together by **C** clamps or machinists' clamps; likewise, the supporting surface may be some suitable part of the work itself. In all cases, however, these two features must exist in some form, and the plane of the supporting surface must be perpendicular to the axis of the guide.

TYPES OF JIGS.

5. Clamp Jigs and Box Jigs. — There are two general types of jigs in common use, each of which has its own sphere of usefulness. The one type is intended for work where the axes of all holes that are cut by the aid of the jig are parallel. The holes need not necessarily be located in the same plane, nor must they be drilled from the same side of the jig. Since jigs of this type frequently resemble some form of a clamp, they are by common consent termed **clamp jigs,** although in some cases the resemblance between the jig and a clamp is very faint, or has entirely disappeared. The other type of jig is intended for work that requires the holes that are to be cut through it, or into it, to be at various angles to one another. Since jigs of this type most frequently resemble some form of a box, the name of **box jig** is commonly applied to any jig intended for holes at angles to one another.

GENERAL REQUIREMENTS.

6. There are a number of general requirements, some or all of which must be partially or entirely fulfilled in the design and construction of any jig. The extent to which any or all of the requirements must be taken into consideration depends on circumstances; each particular case must be decided on its own merits with special reference to the commercial feature. Thus, it may be considered as the height of folly to make a jig worth $50 to do a job worth $20 and which, furthermore, will never be duplicated.

7. One of the most important requirements is the ease of inserting work into a jig and removing it from the jig. Evidently, the easier this necessary operation is performed, the more work can be turned out by an operator when all other conditions remain the same. Ease of insertion and removal under proper management means reduction of the time cost per piece.

8. A jig should be so constructed that it can easily be cleaned, especially those parts of it that act as stops and locate the work properly. Chips getting between the work and the stops will throw the work out of true, and, consequently, will result in an improper location of the holes. While the amount may not be very large, in many cases it will be sufficient to spoil the work. Now, since it is generally agreed that the most stringent orders will fail to make an operator clean the stops of a jig properly before inserting a new piece of work when a large output is demanded, it is considered best to make the stops self-cleaning, as far as can be done, or to design the jig so that it can be cleaned with a minimum effort and preferably without any special appliances.

9. Interchangeability of the work depends, in a great measure, on proper location of the stops, which should be so arranged as to give an invariable location of the work in relation to the guides of the jig. When work that is liable to vary slightly in its dimensions is to be operated upon in

a jig, the stops may occasionally have to be made adjustable in order to accommodate any slight variation in size or shape.

10. Ease of clamping the work to the jig, or vice versa, is a feature that may profitably be studied carefully if a large number of pieces are required to be made in the jig. A rapid clamping arrangement that needs little muscular effort is conducive to a reduction of the time cost per piece.

11. Clamping arrangements require to be so designed that the act of clamping the work to the jig, or vice versa, will not spring the work or the jig. If either is sprung out of true by the act of clamping, inaccurate work will naturally result.

12. Durability of a jig is a requirement that depends on the number of pieces the jig is to be used for as to the extent to which it is to be fulfilled. In general, only such durability should be provided as will serve the extent of service without any serious loss of accuracy.

13. Adaptability to conversion into a combination jig that may be used for either drilling, reaming, or tapping any or all the holes can readily be secured by removable guides of sufficient size, so arranged as to always center themselves during insertion. Since the guides almost invariably take the form of hardened concentric steel bushing, this is, as a general rule, a very easy matter.

14. Capability of accurate duplication is of prime importance not only when the jig is in constant demand, but also when a number of like jigs are required. In the first case, the natural wear and the unnatural abuse a jig is liable to receive will sooner or later call for its duplication; both in the first and in the second case, an accurate duplication can, in almost all instances, be readily provided for by making the jig or jigs either from a master jig preserved for this purpose, or from templets of suitable form made from the first jig and preserved.

15. Sufficient extent of supporting surface will prevent any canting of the jig under the downward pressure of drilling and reaming, and will thus result in a reduction of the breakage of cutting tools. The supporting surface need not necessarily be an unbroken plane; in many cases, three legs, which, of course, will give a steady support in spite of any slight inequalities of the drill-press table, are greatly preferable to an unbroken surface. In other cases, four, and even more, legs whose ends lie in the same plane may prove of advantage, especially when the distance that three legs must be apart in order to prevent canting is beyond the range of the drill press available. In order that the jig may not tip over under the pressure of cutting operations, all guides for the cutting tools must lie well within the polygon that is formed by connecting all adjacent points of support by straight lines.

16. Stiffness is not only desirable for most jigs, but also becomes essential when exact duplication of the work is required. The act of clamping the work to the jig, or the jig to the work, with many designs subjects the jig to bending stresses that tend to deform it. Since these bending stresses cannot be expected to be alike each time the jig is used, it follows that the amount of deformation will vary; consequently, the work done with the aid of the jig will also vary. Stiffness may best be obtained by properly distributing the metal to resist such bending stresses as the jig may be subjected to; the proper arrangement of supports and clamping arrangements will in a measure contribute toward stiffness.

17. Absence of sharp corners means ease of handling; any feature that makes a tool agreeable to the touch may confidently be expected to reduce the time cost per piece.

18. Accuracy of the jig itself, while mentioned last, is the most important requirement. It should always be remembered that any inaccuracy of the jig will be duplicated in the work; and if the cutting tools are loosely guided, the errors may enlarge. While accuracy is essential, there

is such a thing as carrying it to an extreme. The toolmaker should always aim to obtain the accuracy that is essential; any further reduction means a large outlay of money that is generally not warranted by the conditions of the case.

JIG DETAILS.

GUIDE BUSHINGS.

19. Permanent Bushings.—The guides for the cutting tools, which are usually drills, reamers, or taps, most frequently take the form of hardened steel **bushings** set into the jig body. The hole in the bushing is made to fit the drill, reamer, or tap shank closely; the outside of the bushing is exactly concentric with the inside.

20. The bushings may be made in various forms to suit different purposes. Common forms of plain bushings, intended to be driven into suitable holes in the jig body, are shown in Figs. 1 and 2. Referring to Fig. 1, the bushing is seen to be straight inside and outside, except that the end where the drill enters is rounded out to allow it to enter easily. This plain bushing is the cheapest bushing to make, and, if well fitted to the hole that receives it, is thoroughly satisfactory. The only objectionable feature is that when a drill too large for the hole is forced down on the bushing, it is liable to push the bushing through its seat. This is very liable to happen when the jig is used on a multiple-spindle drill press.

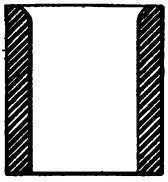


FIG. 1.

21. In order to prevent the bushing from being pushed through its seat, it may be made tapering on the outside, or it may be allowed to project from the seat. The projecting part is then enlarged to form a shoulder. While tapering the outside of the bushing will accomplish the object to be attained, it is an expensive form of bushing to produce.

Likewise, it is expensive to bore the seat for it, especially if great accuracy in the location of its axis is required. On the other hand, a tapered bushing is easily removed.

22. The most common form of a straight bushing with an enlarged head is shown in Fig. 2 (*a*). The shoulder

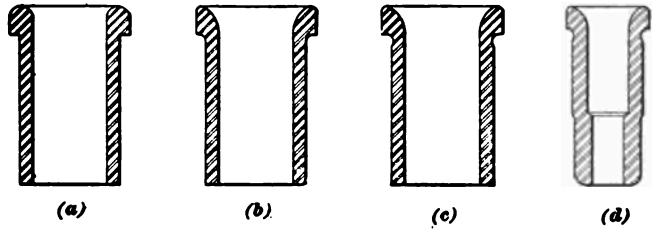


FIG. 2.

under the head is made square. This is objectionable, however, for two reasons. In the first place, in hardening the bushing, a crack is liable to form in the sharp corner; in the second place, while forcing the bushing home into its seat, the head is rather liable to be broken off. The end that receives the drill is rounded off inside and out, usually semicircular, as shown.

23. A better form of a straight bushing is shown in Fig. 2 (*b*). Here a liberal sized fillet is left under the head, which obviates the liability of cracking in hardening, and reduces the liability of breaking the head off while forcing the bushing home. In the bushing shown, the end is rounded out considerably more on the inside than on the outside; this makes it easier for the drill to find the hole and hence is preferable to the semicircular rounding off shown in Fig. 2 (*a*). When the bushing is to be ground on the outside after hardening, it is advisable to very slightly neck it down under the shoulder with a round-nosed tool; when grinding the outside, the emery wheel can then pass clear over the part being ground. The necking down is clearly shown in Fig. 2 (*c*).

24. In many cases, it is necessary for the bushing to project some distance beyond the lower part of its seat, in

order that the point of the drill or end of the reamer may be supported close to the work. In that case, the bushing may take the form shown in Fig. 2 (*d*). As shown in the illustration, it is counterbored part way down, in order to reduce the friction of the drill or reamer against the inner surface of the bushing. The part that serves to guide the cutting tool does not, in general, need to be any longer than twice its diameter.

The bushings so far shown are not intended to be removed except for the purpose of renewal when worn.

25. Removable Bushings.—Any ordinary jig can readily be converted into a combination jig by fitting it with two or more sets of bushings. One set may then be made to fit the drills; the second set may be made to guide the reamers; and the third set may suit the tap shanks. Obviously, the bushing must be easily removable. There are quite a number of ways in which this may be done.

26. The simplest way is to make a straight bushing a sliding fit in its seat and then confine it by a setscrew. While this can be done advantageously in many cases, in others the location of the bushing prevents the use of a setscrew. If that happens to be the case, some toolmakers will fit a tapered bushing to a tapered seat, relying on the friction to hold the bushing in place during the cutting operations.

27. Some forms of a tapered removable bushing are shown in Fig. 3. The simplest form is shown in Fig. 3 (*a*);

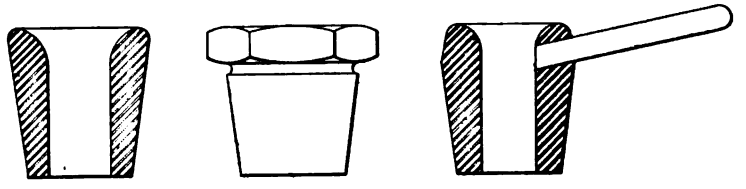


FIG. 3.

the bushing is removed by driving it out with a drift and a hammer. A better form is shown in Fig. 3 (*b*). Here the

bushing is made long enough to project beyond its seat; its projecting part is made hexagonal to receive a wrench, by means of which it may be loosened. In order that the time required for the handling of the wrench may be saved, the projecting part may have a handle permanently attached to it, as shown in Fig. 3 (*c*). The objection to this last form is that, in many cases, the handle may interfere with easy handling of the jig.

28. Tapered removable bushings are not only open to the objection that they are expensive to produce, but also are liable to be thrown out of their true location by any foreign matter, such as chips or waste, getting between the outside of the bushing and its seat. In this respect, a straight removable bushing will have the advantage, since it will push all foreign matter out of its hole during insertion. On the other hand, in the case of the tapered bushing, wear of the seat will not affect the accurate location of the bushings to an appreciable extent.

29. Removable bushings may be threaded on the outside, and may be provided with a hexagonal head, as shown in Fig. 4 (*a*). The seat for the bushing is then

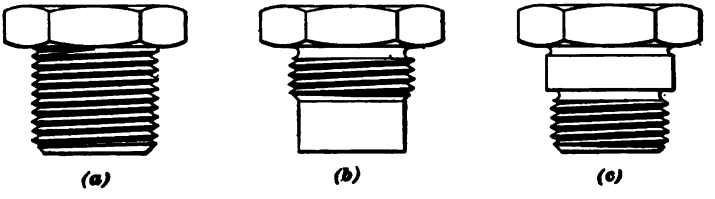


FIG. 4.

chased or tapped to suit. Since the bushing is very liable to change its shape and diameter in hardening, a bushing that is threaded should be finished entirely before chasing the thread in the seat. Obviously, after hardening, it is difficult to grind the thread truly concentric with the hole; for this reason, the use of a bushing of the form shown in Fig. 3 (*a*) is not to be recommended for work that requires very accurate location of the holes. Furthermore, the

unevenness of the thread induced by the hardening process will cause a rapid wear of the thread in the seat, thus destroying the accurate location.

30. A better form of a threaded bushing is shown in Fig. 4 (*b*) and (*c*). Here the thread is not relied on to center the bushing properly, but serves merely as a convenient means of attaching and detaching it. The bushing is centered by a cylindrical part that closely fits a corresponding part of the seat; the thread is made a fairly good fit in the seat. The cylindrical part of the bushing may be either below or above the threaded part; if it is above, the thread in the seat can be tapped clear through, which allows the use of a plug tap. This design of a threaded bushing is preferable for accurate work, since the cylindrical part, after hardening, can be ground true with the hole. While the bushings shown in Fig. 4 all have a hexagonal head, they may be, and occasionally are, made with a large nurled head, and also with a handle similar to that shown in Fig. 3 (*c*).

31. Clamp Bushings. — A jig bushing may serve a double purpose; that is, it may be used for guiding the cutting tool and, at the same time, for clamping the work to

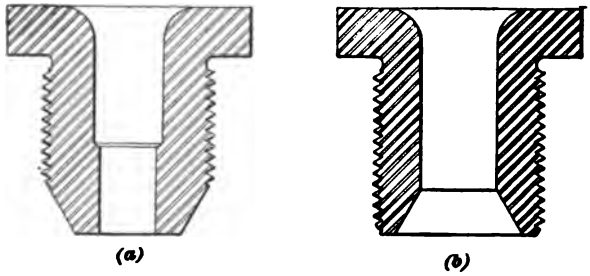


FIG. 5.

the jig body. This is done by making the threaded part of the bushing long enough to allow the end to be screwed down on the work. There are many cases where the adoption of one or more clamp bushings will allow a very simple design of a jig.

32. In some cases where the work has cylindrical projections or a recess, a jig bushing may be made to act as a stop for centering the work properly and clamping it at the same time. Thus, if the work has a cylindrical or conical recess, the lower end of the bushing may be turned conical, as shown in Fig. 5 (*a*). If the work is to be centered by a cylindrical or tapering projection, the lower end of the bushing may be recessed conical, as shown in Fig. 5 (*b*).

33. Size of Guide Hole.—The size of the hole in the bushing has a very important influence on the accuracy with which the holes are drilled into the work. In all cases, the drill or reamer must be loose enough in the bushing so as not to bind and seize. This looseness does not need to be much; if the hole is .001 inch larger than the cutting tool, there is little danger of sticking. How much the hole should be made larger than the drill would be easily determined if it were not for the fact that the commercial sizes of the drills do not, as a general rule, agree very closely with their nominal size. While the variation between different drills of the same nominal size is not very large, and not sufficient to be appreciable for ordinary work, this variation becomes quite appreciable when accurate work is to be done by jig drilling.

If a number of drills of the same nominal size are measured, some will be found over size, some under size, and, perhaps, a few correct size. The toolmaker now has the choice of several methods of procedure. He may make the guide hole sufficiently large to fit the largest drill in the lot, which involves a consequent serious looseness of fit of the under-size drills; or he may make the guide hole standard size and stone down all drills that are over size; or, further, he may make the bushing to suit the smallest under-size drill, and stone all other drills down to suit this size.

34. Which of these methods is to be adopted is purely a question of the accuracy with which the holes are to be located, and the accuracy with which the drilled holes are to represent their nominal size. When accuracy of location

is the most essential factor, the third method is preferable; if keeping the holes to the standard size is deemed most important, the second method may be adopted; and for a comparatively rough job, the first method may be chosen. In choosing a method, it is to be observed that great accuracy, in regard to keeping all holes drilled with the aid of the jig to the same size, must not be expected by drilling; as well known, a drill can drill a hole considerably larger than itself if it is ground so that its point is out of center.

35. Material for Bushings.—The material to be chosen for making the bushings depends on the resistance to wear that is deemed essential. Hardened tool-steel bushings left as hard as fire and water can make them will resist wear better than machinery-steel bushings that have been case-hardened with cyanide or prussiate of potassium. Machinery steel will answer very well for bushings that are intended for temporary jigs; if the jig is in constant use, however, it is usually advisable to choose tool steel and harden the bushings.

36. Grinding Bushings.—Since the hardening process not only changes the size but also the shape of the bushings, they should be ground both inside and outside after hardening, if great accuracy in the central location of the guide holes in reference to the seat is deemed essential. In many cases, however, dependence can be placed on the fact that forcing the bushing home will partially correct any deviation from roundness induced by hardening, especially if the walls of the bushings are thin. In that case, the bushings may be lapped to size after they have been forced home.

CLAMPING DEVICES.

37. Jigs are supplied with **clamping devices** of various forms for one or both of two different purposes: to clamp the work to the jig body or to clamp some part of the jig made movable to provide for inserting and removing work.

38. Clamps intended for the purpose first mentioned may be designed in various ways to suit different conditions. For some work the hook bolt shown in Fig. 6 is very well adapted, being cheap in construction and easily applied. The bolt proper passes through a hole in the jig, which it fits closely. It is made long enough to have the head hook over some projecting part of the work, and may be supplied with a wing nut as shown, or have an ordinary hexagonal nut. In some cases, a large nurled nut may be of advantage. The greatest clamping pressure can be obtained with a hexagonal nut and a wrench; a moderate pressure can be obtained with the wing nut or the nurled nut. However, the wing nut or nurled nut allows the hook bolt to be applied more rapidly. It will be understood that in order to allow the work to be inserted or removed, the loosened hook bolt is turned so that its head is away from the work; when the work has been inserted, the head is turned toward the work and hooks over it. The clamping is then done by screwing up the nut.

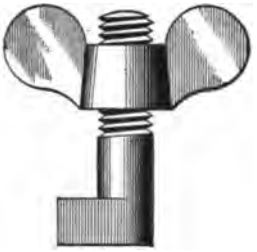


FIG. 6.

39. In jigs that partially or entirely surround the work, it is most commonly held in place by setscrews, which may be designed in several ways. When drop-forged thumbscrews are available, they are generally used, since comparatively little work is required to finish them. When these cannot be obtained, the setscrews may be made as shown in Fig. 7 by driving a cylindrical pin into a hole drilled through the head of the screw. In many cases, the ordinary setscrews that can be bought in the market may be used. These, however, require a wrench for tightening, and hence are not so readily used as thumbscrews, or the screw illustrated in Fig. 7.



FIG. 7.

40. Fig. 8 shows a common clamping arrangement for locking two parts of a jig together. The thumbscrew shown

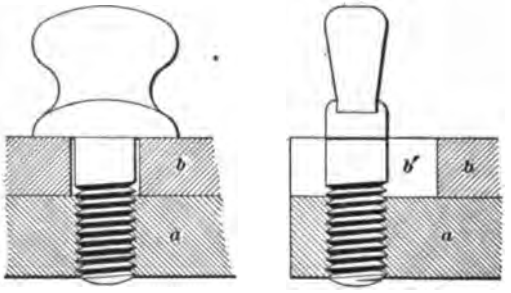


FIG. 8.

is screwed into a tapped hole in the jig body, as *a*. The shank passes through a slot *b'* in the movable part *b* of the jig. This slot is wide and long enough to allow the head to clear it when the screw has been given a quarter-turn from the position shown. Evidently, this is a very rapid clamping arrangement. The only objection is that, as the threads and the bearing surfaces wear, the head will finally come in line with the slot in the movable part.

41. Fig. 9 shows a hinged bolt, which is hinged to the stationary part *a* of the jig by means of the pin shown. The

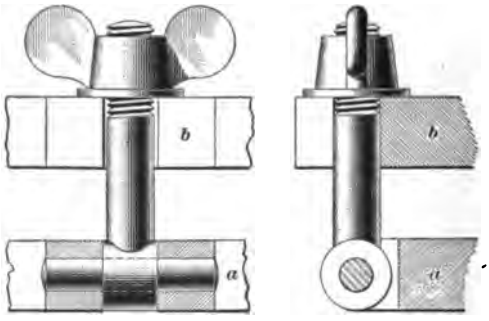


FIG. 9.

bolt passes through a slot in the movable part *b*, open on one end, and is provided with a nut and washer. The nut may

be a wing nut, as shown, or a hexagonal or nurled nut. Wear of the bearing surface or of the pin joint does not affect the clamping. As the nut must be unscrewed some distance to allow the bolt to be swung clear of the slot, this arrangement is not quite so rapid as that shown in Fig. 8.

42. Fig. 10 shows a hinged cam-lever pivoted to the stationary part *a* of the jig. Its shank passes into a slot in the

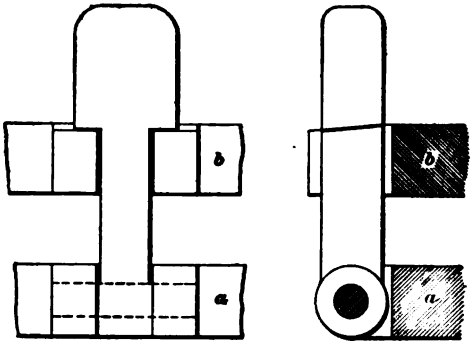


FIG. 10.

movable part *b*; the bearing surfaces of the head engage inclined surfaces of the movable part. Where extreme rapidity of clamping is desired, this design can be recommended.

STOP-PINS.

43. In order to prevent any shifting of the work in the jig during the cutting operations, one or more **stop-pins** may be provided. These are usually made cylindrical, and are closely fitted to the guide bushing. They should be provided with a suitable handle to facilitate withdrawal. To prevent shifting of the work, a stop-pin is pushed through the bushing into the hole in the work as soon as the hole has been drilled. Since the work must be confined at least in two places to surely prevent any liability of shifting, two stop-pins are often provided. It is a good idea always to select the holes that are the farthest apart for the stop-pins.

JIG MAKING.

EXAMPLES OF JIG DESIGN.

44. Owing to the innumerable shapes that the work a jig is intended for may have, no specific directions can be given as to the design of a jig. The general requirements previously given should in each case be fulfilled to the extent that the circumstances render advisable. The designs given here will serve as suggestions to the toolmaker, but they must be modified to suit conditions and requirements.

45. The simplest form of a jig is shown in Fig. 11. The jig simply consists of a flat plate made of suitable material. The outline of the jig is the same as that of the work; holes are drilled in the jig to serve as guides. The jig is intended to be laid on the work and is then clamped to it by any suitable and convenient means so that its outline coincides with that of the work.

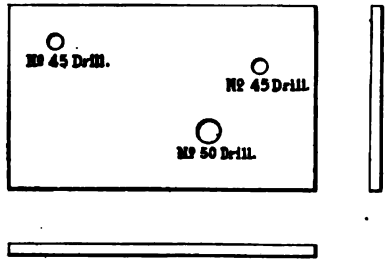


FIG. 11.

46. Such a jig is cheap, and will serve well for flat work where extreme accuracy in the location of the holes is not essential. For small work it will last quite well if made of sheet tool steel and hardened all over. When it is to be used for a small number of pieces, it may be made of machinery steel and the holes case-hardened. When the holes wear, either a new jig must be made or the holes counterbored to receive hardened steel bushings.

47. In the latter case, the jig takes the form shown in Fig. 12, which may be considered as the second step in the development of a jig. Since the bushings can be replaced easily when worn, the center-to-center distance of their axes can be accurately preserved. Beyond this fact, the design

shown is not particularly more advantageous than the one shown in Fig. 11, except that it may be used for sizes that would prevent heating and hardening the entire jig.

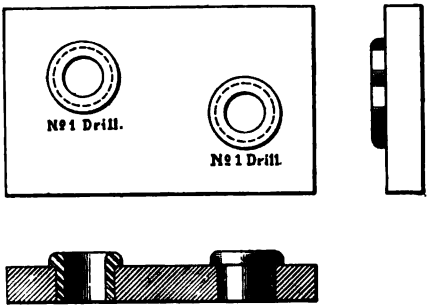


FIG. 12.

48. Fig. 13 illustrates a more advanced form, in which stops have been added for the purpose of alining the jig on the work. In this particular instance, the stops are formed by flanges *a*, *a* and pins *b*, *b*, so placed as to suit the outline of the work. If the different pieces of work are quite uniform, as, for instance, if the outline has been finished by profiling, punching, or milling, quite accurate work

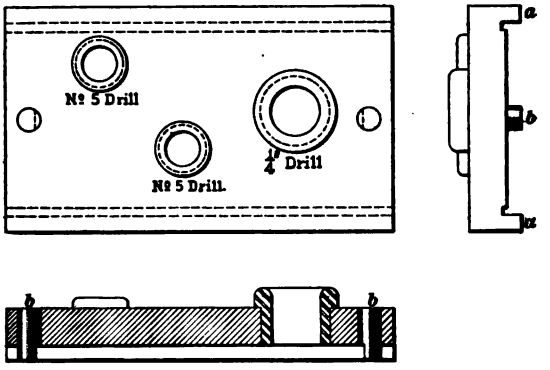


FIG. 13.

can be done in a jig of this design. In many instances, it is not even necessary to clamp the work to the jig, as the stops will often be sufficient to prevent shifting of the jig.

49. A further development of a jig is shown in Fig. 14, where a clamping attachment has been added. The jig is here made in two parts, hinged together at one end. The

pressure of the hand of the operator is intended to clamp

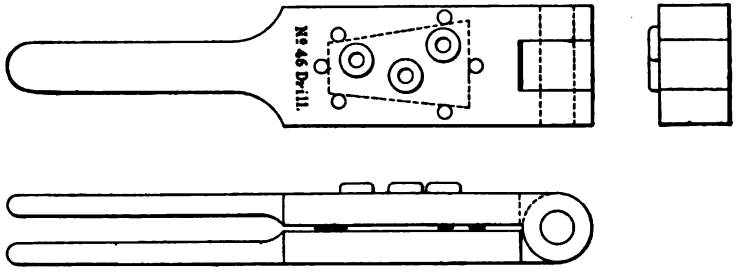


FIG. 14.

the work to the jig; stop-pins placed to suit the outline of the work insure an unvarying location of the holes in refer-

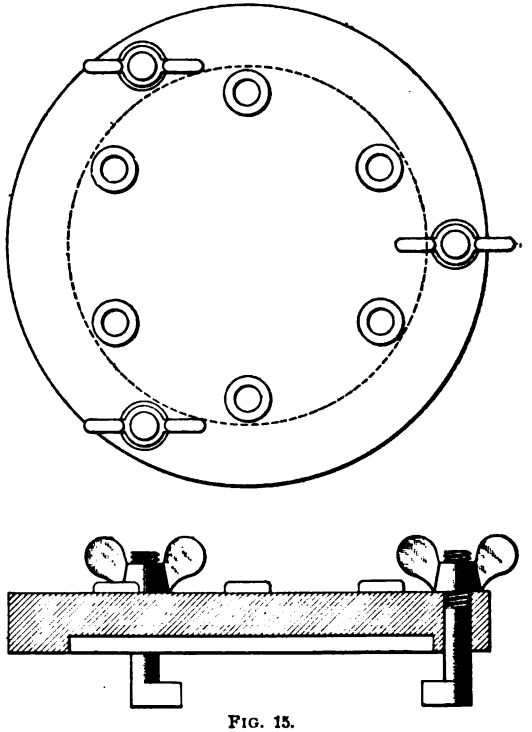


FIG. 15.

ence to the outline. A jig of this kind is well adapted for drilling holes through small flat work of uniform thickness.

50. Fig. 15 shows a jig design well adapted for drilling holes through flanges. The jig body is recessed to go over the flange, and the jig is attached and clamped by means of the hook bolts shown. Attention is called to the position of the hook bolts in reference to the bushings. They should always be so located that neither the head of the hook bolt nor the nut can ever come in the way of the drill, reamer, or tap that is intended to be guided by the bushing. Jigs of this design are readily modified to be alined to a bored or cored hole in the work by providing the lower surface with a projection of suitable shape instead of the recess shown.

51. With the exception of the jig illustrated in Fig. 14, all the designs thus far shown depend on the work itself for furnishing a supporting surface to sustain the downward thrust of the cutting operations. Fig. 16 shows a jig in

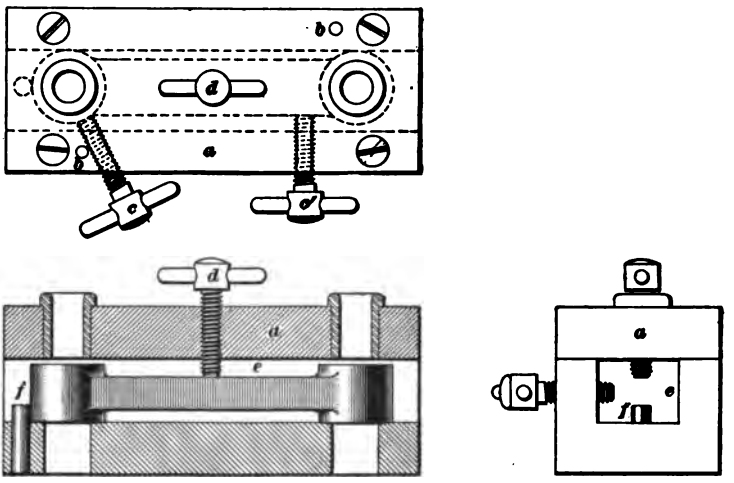


FIG. 16.

which the work is placed within the jig, and where, consequently, the thrust is taken by a suitable surface of the jig. Referring to the illustration, it is seen that the jig is made of two parts for the sake of convenience in machining it. The cover *a* is fastened by the screws shown; an invariable location of the bushings in reference to the stops is insured

by dowel pins *b*, *b*. This precaution is necessary when the stops are contained in a part of the jig that is separate from that which carries the bushings. The work is pushed against the stops by the setscrews *c* and *c'*; it is held down by the setscrew *d*. In this case, the surface *e* of the jig has been selected as a suitable stop to gauge the location of the work sidewise; its longitudinal location is gauged by the stop-pin *f*. It will be observed that the setscrew *c* is placed at an angle with *c'*. Owing to the way in which it bears against the work, the tightening up of the setscrew will not only push the work against both stops, but will also prevent any longitudinal movement, thus doing away with the necessity of placing another setscrew at the right-hand end of the jig.

The design shown possesses several disadvantages. In the first place, it is rather difficult to clean it properly; in the second place, it is easy to spring the work out of true with the setscrew *d*.

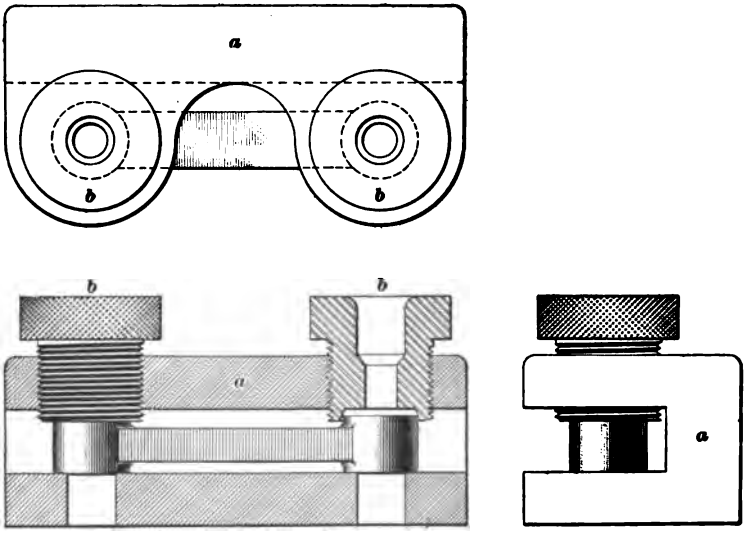


FIG. 17.

52. Fig. 17 shows how a jig may be made for the same piece that the design shown in Fig. 16 was intended for, in

order to overcome the objectionable features of that design. The jig body *a* is composed of one piece in this instance, which is open in front to allow easy insertion and removal of the work, and to make the jig accessible for cleaning. In order to do away with clamping screws and stops, the bushings *b*, *b* themselves are made to act as such. This makes a very simple and cheaply made jig, well adapted for work like that shown clamped in the jig.

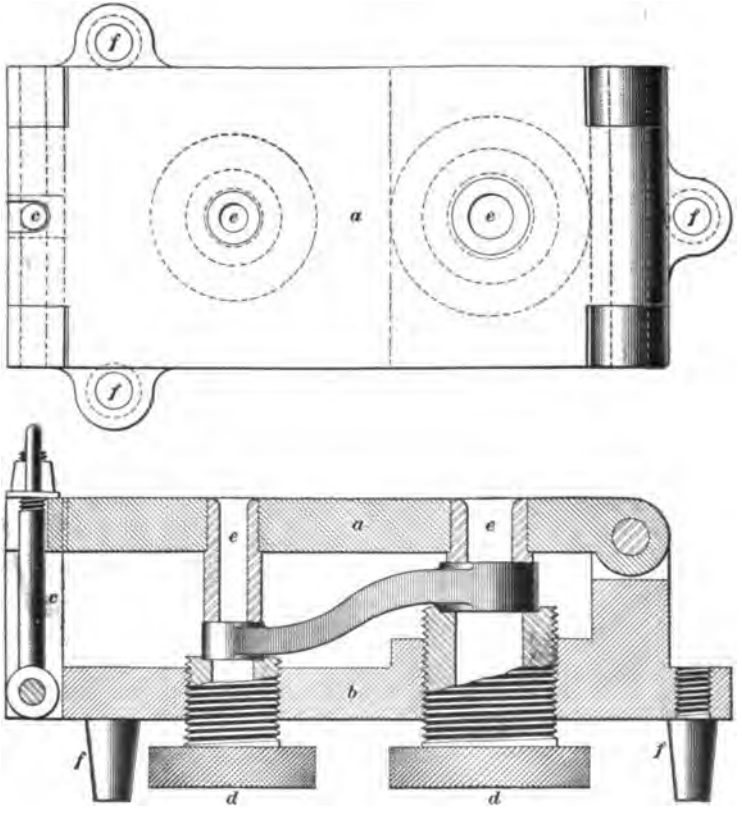


FIG. 18.

53. Ease of insertion and removal and accessibility for cleaning may often be secured by making some part of the jig movable. Thus, in Fig. 18, the top part *a* of the jig is

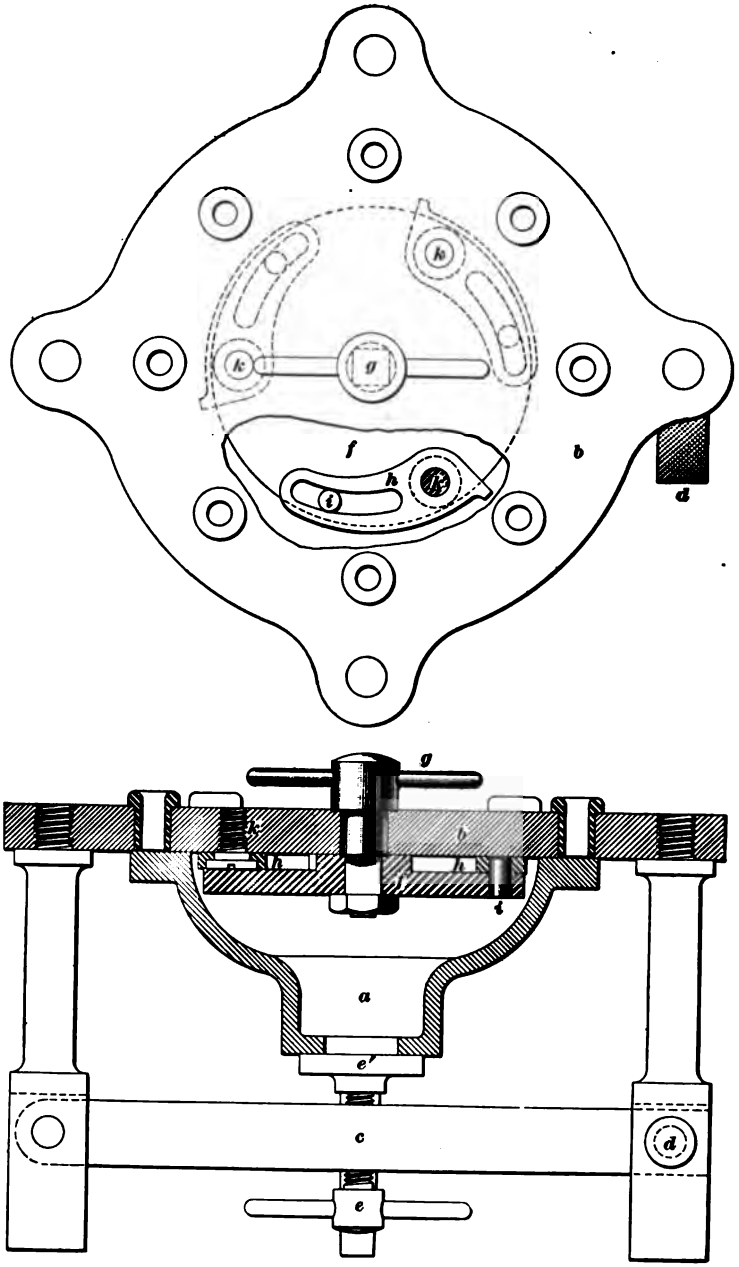


FIG. 19.

hinged to the body *b*; the two parts are clamped together by the hinged bolt *c*. In order to show the slot in *a* clearly, the wing nut and washer of this bolt are shown removed in the plan view. The work is supported against the thrust of the cutting operation by clamping bushings *d*, *d*, the ends of which are chamfered in order to act as stops at the same time. The guide bushings *e*, *e* in this case have a shoulder on their lower end for the purpose of preventing the upward pressure of the clamping bushings from moving them. Three legs *f*, *f* are fastened to the jig body; these legs rest on the drill-press table while the jig is in use. They must be made long enough to insure that the lower end of the clamping bushings will always come clear of the table.

The design is shown applied to work in which the holes do not lie in the same horizontal plane; it may be applied to other work, however. Every part of the jig is accessible; the work is automatically centered and the disadvantages of threaded guide bushings are avoided. The liability of springing the jig in the clamping operation is greatly reduced by providing the clamping bushings with nurled heads on which the fingers of the operator will slip before he can tighten them sufficiently to spring the jig out of true.

54. Fig. 19 shows a form of jig that is largely used for drilling holes in the flanges of work that has a cross-section similar to that shown in the illustration, where *a* represents the work. Since three legs would, in this case, make the jig rather complicated, four are used. The jig body *b* is simply a flat plate into which four legs are screwed. Two opposite legs are slotted to receive the yoke *c*, which is hinged at one end, and secured in position at the other end by a removable pin *d*. This yoke carries the setscrew *e*, by means of which the work is clamped to the jig. When the work has a hole in line with the setscrew, the latter may terminate in a circular plate, as *e'*. To insert or remove the work, the jig is turned upside down; the pin *d* is then removed and the yoke swung out of the way. When the

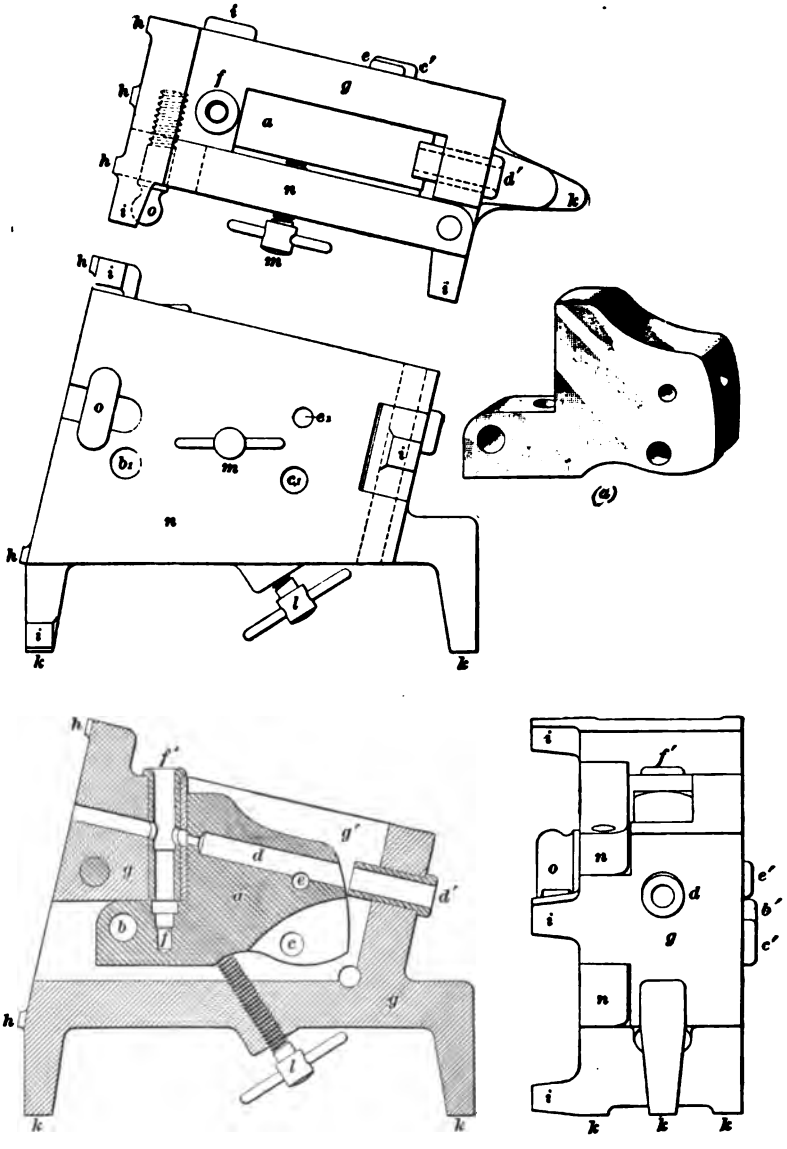

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FIG. 20.

jig is used for castings, which, as well known, are bound to vary slightly in size, the jig may be provided with a self-centering arrangement.

Referring to the figure, *f* is a plate that can be rotated by means of the handle *g*. This plate carries three pins *i*, *i* that enter slots formed in the jaws *h*, *h*. These jaws are pivoted to the jig body by screws, as *k*, *k*, and their axes are placed nearer the axis of rotation of the plate *f* than the pins *i*, *i*. In consequence of this, a right-handed rotation of the plate will cause the jaws to swing around their fulcrum screws until they come against the work, which is thus centered. The design of centering arrangement is not given as the best one that could be devised, but simply shows one way of accomplishing the object to be attained.

55. All the jigs so far shown are intended for drilling work in which the axes of all holes are parallel. Fig. 20 shows a jig designed for drilling holes in three different directions in one chucking. Referring to Fig. 20, the work *a*, which is shown in perspective in Fig. 20 (*a*), is to be pierced by the holes *b*, *c*, *d*, and *e*, and is to have the blind hole *f* drilled to a clearance and tapping size. This hole *f* is recessed, as shown, in a separate operation. In the work shown, it is essential that the holes should be located correctly in reference to the two surfaces in contact with the stops of the jig body.

To allow the work to be easily inserted and removed and to give accessibility, the jig is made in two parts, of which the part *g* carries all the bushings, stops, and the legs that form the supporting surfaces. For drilling the hole *d*, the jig is supported on the three legs *h*, *h*, *h*, the plane of which is perpendicular to the axis of *d*. For drilling the holes *b*, *c*, and *e*, the jig is supported on the legs *i*, *i*, *i*. Three points of support, as *k*, *k*, *k*, are provided for drilling the hole *f*. An examination of the shape of the work shows that it can be held against the stops in two directions by a setscrew placed as *l*; it is held against the surface *g'* by the setscrew *m*, which is located in the movable hinged part *n* of the jig.

The part *n* is clamped by the clamp screw *o*. The guide bushings for drilling the holes *b*, *c*, *d*, *e*, and *f* are shown at *b'*, *c'*, *d'*, *e'*, and *f'*, respectively. As far as the holes *d* and *f* are concerned, the holes have two sizes each. The bushings for them are made to the larger sizes, and drilling is continued with smaller drills after the holes have been drilled their large size to the correct depth. The bushing *f'* is pierced by a clearance hole; since this hole penetrates above the guiding part of the bushing, there is no particular objection to piercing the bushing. Clearance holes as b_1, c_1, and e_1 are drilled through the movable cover in line with the bushings for the escape of chips.

LOCATING HOLES.

LOCATING HOLES FROM A DRAWING.

56. The problem of correctly locating the holes that receive the guide bushings presents itself usually in one of two different ways. Either the holes are to be laid out from a dimensioned drawing or they are to be transferred from a model of the work. The choice of method of procedure depends on the accuracy required and also on other conditions, such as the facilities at hand and the nature of the work.

57. When extreme accuracy is not required, the centers of the holes are laid out in the same manner in which the machinist lays out his work, that is, by scribing lines with scriber, surface gauge, etc. In that case, all dimensions are transferred from a steel rule. Since the intersections of the scribed lines represent the centers of the holes, they are carefully marked by a fine prick-punch mark and a witness circle slightly larger than the proposed hole is drawn from each prick-punch mark as a center. There is now the choice of two methods for putting the hole through the jig. The holes may be drilled and reamed in the drill press, or they may be bored in the lathe. Drilling and reaming the holes in the drill press has the advantage of cheapness, but will

insure only a fair degree of accuracy in the location of the holes, since any lack of homogeneity in the metal will cause the drill to run to one side or the other. With reasonable care in laying out the holes, and in the subsequent drilling and reaming, the holes, as a general rule, may be located within a limit of variation of .005 inch. If extreme care is used, the holes may be located within .003 inch; this may be considered as the limit of accuracy attainable by this method.

58. The relatively low degree of accuracy attainable by the use of the method just given is due to the existence of two errors, neither of which can be eliminated entirely by design, although, as the result of accident, either or both may occasionally be so small as to be insensible. One of these errors is that due to an accumulation of the individual errors of each successive stage of the laying-out process; this accumulation of errors finally appears as a lateral deviation of the axis of the prick-punch mark from the true location of the axis intended to be represented by it. The second error is due to running out of the drill, which is caused by lack of homogeneity of the metal or by carelessness, and, frequently, by a combination of both. Either error can be minimized by careful work; the extent to which it can be minimized is a quantity whose relative value depends entirely on the skill of the toolmaker.

59. In order to reduce the limit of variation, a modification of the method previously given may be employed. This modification will neither reduce nor eliminate the error of laying out, but will greatly reduce the error of putting the hole through the jig. In addition, it will insure that the axis of the hole is perpendicular to the supporting surface. After laying the holes out properly, the jig is strapped against a true-running straight face plate and is trued up successively to the various prick-punch marks by means of a sensitive center indicator. After each truing up, a hole is drilled clear through; the hole is then finished by careful boring with a sharp tool. In order to do accurate work, it

is necessary to counterbalance the weight of the jig by attaching a suitable weight to the face plate, and opposite the jig. The boxes in which the lathe spindle runs must be set quite close, and all end movement of the lathe spindle should be taken up. Also examine the belt lacing; if this shows a decided lump, relace the belt smoothly. Otherwise, every time the lacing strikes the cone of the live spindle it will cause the latter to jump to the extent of the looseness between the spindle and its boxes.

With extremely careful work in laying out, truing up, and boring, the holes may be located within a limit of variation as small as .0015 inch. The method given is limited in its application by the swing of the largest lathe available.

60. If the holes in the jig are to be located closer than is usually possible by the method given in Art. **59**, contact measurements, as far as practicable, must be substituted for measurements transferred by scribed lines. The tools required are a micrometer caliper of sufficient capacity or a measuring machine, and a number of annular circular steel buttons. These buttons may be of any convenient size; a good size is $\frac{1}{2}$ inch outside diameter, $\frac{1}{4}$ inch inside diameter, and $\frac{1}{4}$ inch thick. They are attached to the work by means of fillister-headed screws of about $\frac{3}{16}$ inch diameter; No. 10–32 machine screws will be found very convenient for this purpose. The buttons should be made of tool steel and they should be ground truly circular after hardening.

61. The method of using the buttons for a case where all holes are to be in the same plane is perhaps best shown by a concrete example. Let Fig. 21 be a working drawing of part of a jig in which the holes *a* and *b* are to be located with reference to each other and to the surfaces *c* and *d* within

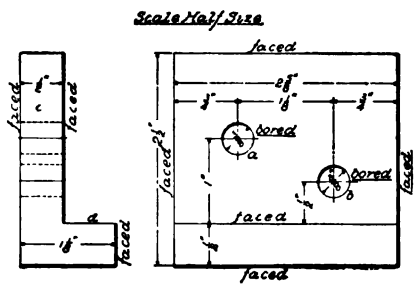


FIG. 21.

as small a limit of variation as possible. The position of the holes is first laid out by scribing lines with the aid of a surface gauge or scribing block, as *e* in Fig. 22, setting the point of the scriber *f* to a steel scale resting on the surface plate and

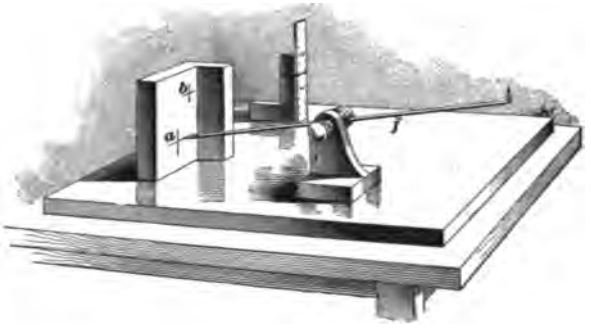


FIG. 22.

held upright by being placed against a square, as shown. For convenience, the scale may be secured to the square by one or two rubber bands. The centers of the holes having been laid out, they are center-punched and then drilled and tapped for the size of machine screw chosen.

The buttons, as *a'* and *b'* in Fig. 23, are now attached by means of the screws. Since the hole in the button is larger than the diameter of the screw, it follows that the buttons can be shifted a limited amount. Assume that the buttons are both .5 inch diameter. Then, to place the button *a'* at a distance of 1 inch (see Fig. 21) from *d*, first make a gauge, as *c*, Fig. 23, equal in length to the difference between the radius of *a'* and the given dimension, or $1 - \frac{.5}{2} = .75$ inch long. Then, shift the button until the gauge *c*, when perpendicular to *d*, will just touch *d* and *a'* with the same degree of tightness with which it fits the micrometer.

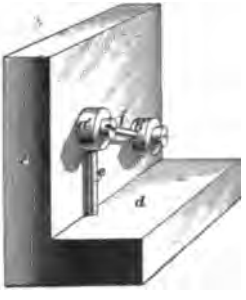


FIG. 23.

To locate the axis of *a'* in reference to *c*, the jig may be

placed on a surface plate with the surface *c* resting on the plate. Then, in a manner similar to that employed to locate the button in reference to *d*, it may be located at the proper distance from *c*. The screw may now be tightened and the proper adjustment of the button tested again, since the tightening process is liable to shift it.

The location of *b'* in respect to *d* is simply a repetition of the method employed to locate *a'*. When we come to locate it in reference to the button *a'*, two ways may be employed. We may obtain the center-to-center distance between *a'* and *b'* by trigonometrical calculation, subtract the sum of the radii of the two buttons from it and file a wire, as *f*, Fig. 23, to it, and use this wire to aline *b'*. If this is not feasible or desirable, the button *b'* may be located from the surface *c* in the same manner that *a'* was located in reference to that surface. After locating *b'*, it is clamped tightly to the piece and then tested again. If found correct, the piece may now be strapped to the face plate of a lathe and trued up by shifting until one of the buttons runs true ; that is, until its axis coincides with the axis of the lathe spindle. An indicator is indispensable for this.

It may be well to call attention to the fact that, in order to do any accurate work, the lathe spindle must be truly cylindrical and must fit the boxes very closely. The face plate should also be counterbalanced and the belt lacing properly fixed. After truing up, the button may be removed and the hole bored to the required size. The other hole is similarly treated.

62. When the guide bushings do not lie in the same horizontal plane, as, for instance, when a jig having the cross-section shown in Fig. 24 is to receive guide bushings in the places indicated by the dotted lines at *a* and *b*, respectively, it is evident that no direct-contact measurement between the buttons is feasible if they are attached to the top and flange of the jig. In such a case, a temporary flat plate, as *c*, may be attached and the buttons may then be fastened to this plate in order to bring them all into the

same plane. This plate must be straight and parallel, and so fastened as to preclude any possibility of shifting. After boring all holes through plate and jig, this plate may be saved; it will be of great value in duplicating the jig. To duplicate the jig, the plate is then fastened in the same

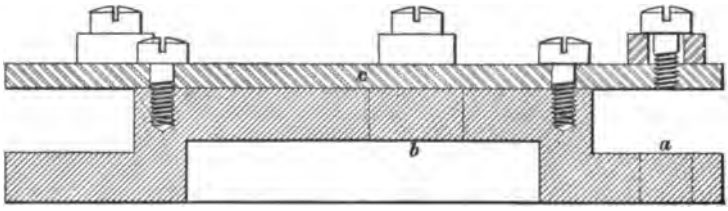


FIG. 24.

relative position it occupied on the jig first made; the jig is next trued up by the holes in the plate, using an indicator for the purpose of obtaining accuracy, and the holes are bored.

LOCATING HOLES FROM A MODEL.

63. When a jig is to be made to suit the holes in a model, there is usually a choice of several ways in which these may be transferred. The choice of method is influenced greatly by the shape of the work and the character of the holes in it. When the holes pass clear through the work, work and jig may often be clamped together and the holes transferred by drilling and reaming. Start the hole with a drill that fits the hole in the work; when the jig has been spotted sufficiently deep, use a drill one size smaller and finish with a rose reamer that closely fits the hole in the work. All holes having been drilled and reamed, enlarge the holes in the jig by counterboring with a counterbore whose teat closely fits the reamed hole.

64. When the hole in the work is blind, i. e., when it does not pass clear through, as the hole *a* in Fig. 25, or when other circumstances prevent a drill and reamer from passing through the hole from below, as in case of the

hole *b*, a different way of transferring must be adopted. The most common way is to transfer the holes as accurately as circumstances permit to the outside of the jig by scribed lines. A so-called pilot hole, as *a'* or *b'*, somewhat larger than the hole in the work, is next drilled through the jig.

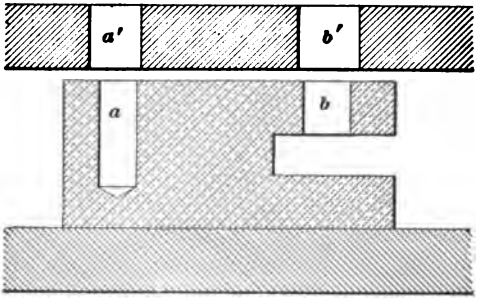


FIG. 25.

The jig is then strapped to the face plate and trued up by the holes in the work, or, if an indicator cannot be applied to the holes, a cylindrical plug is inserted and the indicator applied to the plug. After the jig is trued, the plug is removed; the hole in the jig is then brought in line with that in the model by careful boring.

65. When the jig is too large to be swung in the lathe, or when no lathe is available, the holes in the jig may be brought in line by counterboring. In some cases, the holes

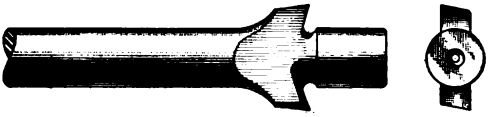


FIG. 26.

in the model are deep enough to allow an ordinary counterbore to be used; to insure good work, the teat of the counterbore must be a good fit in the holes in the model. Owing to the fact that the holes are not in line, the counterbore does not cut equally all around and will have a tendency

to spring toward the side where the least metal is to be removed. This tendency can be counteracted to a great extent by forming the cutting edges in the manner shown in Fig. 26. That is, instead of making them at a right angle to the axis, they are to be inclined inwardly toward the shank. With a counterbore made as shown, and with a reasonable degree of care while using it, a very good job can be done.

66. When the holes in the model are not deep enough to allow an ordinary counterbore to be used, a special counterbore made as shown in Fig. 27 can often be employed. In this case, the teat is stationary; it is formed by a well-fitting plug inserted in the hole in the model. The counterbore is bored out to fit this plug and revolves around it in use. Its cutting edges should be formed in the same manner as those of the counterbore shown in Fig. 26, and for the same reason.



FIG. 27.

MARKING AND RECORDING JIGS.

67. Marking Jigs.—An important element in making jigs and fixtures is the marking by which they may be identified. All jigs and fixtures should have the name of the machine and the part of the machine for which they are intended stamped on them, so that any person can tell just what piece of work the jig is intended for. It is also well to stamp the size of all drills and reamers opposite the bushings through which they are to be used.

68. Recording Jigs.—It is well to give all jigs consecutive numbers and to keep a record of them in proper books or card indexes. In some cases information concerning the jig is entered on the drawing. Each jig should have its place in the tool room or storage room, and this should be entered in the record.

INDEX

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Belting, 24 45" means that belting will be found on page 45 of section 24. As there are two papers in this volume bearing the section number 18, all items referring to the paper on *Grinding* have the letter "*G*" following the section number in this index.

A	Sec.	Page
Abrasive materials	18*G*	7
Abrasives, Artificial	18*G*	10
Accumulation of errors	25	10
" of errors, Reduction of	25	12
Addendum	17	6
" circle	17	6
Adjustable dies	26	6
" reamers	26	11
" reamers	26	28
" taps	25	30
Alligator wrench	21	34
Allowance for different classes of fits	22	35
Angle of clearance for hob-forming tool	27	21
" Originating a 60°	28	30
Angles, Laying out of	28	20
" Originating	28	26
Angular gauges, Names of	28	20
Animal oils, Objections to	24	36
Appliances for erecting an engine on foundation	28	39
Arc of contact of belt	24	46
Artificial abrasives	18*G*	10
Automatic cross-feed for grinding machine	18*G*	52
" dies	30	9
" gear-cutter	18	13

B	Sec.	Page
Babbitt metal	24	61
" metal, Composition of	24	61
Babbitt metal, Lubricants for cutting	24	43
" metal, Making of	24	61
" metal, Melting of	24	62
Babbitting, Form of box for	24	63
" jigs	24	65
" journal brasses	24	68
" Mandrels for	24	64
Back of a file	20	28
" rest for grinding	19	28
Backing off attachment for lathe	27	11
" off cutters, Methods of	19	59
" off machine	27	11
Backlash	17	6
Ball bearings, Grease for	24	36
" peen hammer	20	2
Bars, Pinch	24	2
Bearings, Curing of hot	24	38
" Distance between, on shafting	24	50
" Grease for ball	24	36
" Oil for cleaning	24	37
Bed, Leveling a planer	23	14
" of a punching machine	29	3
Bell chuck for grinding	19	44
Bellied file	20	28
Belt, Arc of contact of	24	46
" Effective pull of a	24	46
" Length of	24	45
" speed	24	48
Belting	24	45

	Sec.	Page
Belts, Double	24	49
" Horsepower of	24	48
" Polishing	18G	20
" Width of	24	48
Bench centers	20	5
" Post work	20	16
" work	20	1
" work, Tools used in	20	2
Benches for holding work	20	12
" Permanent work	20	13
" Portable work	20	14
Bending	30	2
" dies	30	6
Bends	24	11
Benzine	24	38
Bevel gear-blanks, Laying out of	17	38
" gear-calculations	17	35
" gear-cutter, Bilgram	18	30
" gear-teeth, Convergence of	17	35
" gears	17	33
" gears, Conjugate	18	38
" gears, Cutting, with formed cutters	18	14
" gears, Herring-bone	18	38
" gears, Laying out	17	35
" gears, Laying out tooth curves for	17	39
" gears, Molding milling	18	36
" gears, Pitch circle for	17	34
" gears, Pitch cones for	17	34
" gears, Selecting cutter for	18	14
" gears, Setting milling machine to cut	18	15
" gears, Spiral	18	38
Bilgram bevel gear-cutter	18	30
Black diamond	19	68
" lead	24	38
Blackening iron and steel	24	71
Blackwall hitch	24	11
Blank holder	30	14
Blanks for drawing and forming, Size of	30	26
Block and tackle	22	39
" Filing	20	28
Blocking	22	1
" Cylindrical iron	22	4
" Iron	22	3
" Wooden	22	2
Blocks, Adjustable parallel	22	5
" Chain	22	39
" Parallel	22	3
Bluing iron and steel	24	70
Blunt file	20	28
Boiler locomotive, Placing of	23	56
" Placing of, in locomotive erection	23	46
" Testing of locomotive	23	52
Bolster of a punch	29	3
Bonds for emery wheels	18G	11
Bort	19	68
Bowline knot	24	13
Box jigs	31	2
" Rebabbitting a	24	68
Boxes, Tote	24	56
Brass, Square-thread taps for	25	38
Brasses, Babbitting journal	24	68
Brazing broken castings	24	33
Breast drill	21	9
Brick floors for erecting	22	17
British classification of files	20	32
Broach, Simple square	21	9
" teeth, Angle of	21	14
Broaches, Grinding the teeth of	21	11
" Lubrication of	21	14
" Making a set of	21	11
" Use of several, in a set	21	10
Broaching	21	9
"	30	31
" keyways	21	12
" Machine	21	13
Brown & Sharpe gear-cutters	18	6
Browning iron and steel	24	71
Brush wheels	18G	24
Buffing	18G	22
" Applications of	18G	23
" Distinction between polishing and	18G	22
" Material used for	18G	23
" wheel mount	18G	24
" wheels	18G	22
Bulldozer dies, Special	30	8
Bushing emery wheels	18G	13
" Facing of, by grinding	19	18
Bushings, Clamp	31	10
" Grinding of	31	12
" Guide for jigs	31	6
" Material for	31	12
" Permanent guide	31	6
" Removable jig	31	8
" Size of guide hole in	31	11
Button method of locating holes in a jig	31	28

C	Sec.	Page
Caliper gauge, Grinding a	19	22
" Gear-tooth	18	17

	Sec.	Page
Cam for making formed cutters	27	16
Cant file	20	33
Cape chisel	20	18
Capscrew heads	24	72
Carborundum	18G	10
Card, File	20	47
Carriage, Squaring lathe, with spindle	23	7
Castings, Brazing of	24	33
" Cleaning of	24	18
" Pickling solutions for	24	19
" Precautions in regard to planer	23	12
Catspaw	24	11
Celluloid wheels	18G	13
Center, Cup	20	4
" indicator	25	18
" punch	20	2
Centers, Bench	20	5
" Driving work between, on grinding machine	19	16
" Grinding of	19	24
Chain block, Differential	22	40
" blocks	22	39
" hoists	24	5
" tongs	21	34
Chaser hobs	25	29
Chatter marks from grinding	19	9
Chattering of reamers	26	12
Cheapening work by duplication	24	29
Chipped castings, Patching of	24	32
Chipping	20	19
" Examples of	20	21
" Holding hammer and chisel in	20	19
" keyseats	20	22
" large flat surfaces	20	22
" Pneumatic hammer for	20	24
" strip	20	24
Chisel, Cape	20	18
" Diamond-pointed	20	18
" Flat	20	16
" Gouge	20	18
" Grooving	20	18
" Holding, while chipping	20	19
" Side	20	18
Chisels, Cold	20	16
Chuck, Bell, for grinding	19	44
" Grinding work held in a	19	24
Chucks for use in grinding	19	44
Chucks, Special, for grinding	19	25
Chucking reamers	26	27
Circle, Addendum	17	6
" Dividing, by assembly of equal pieces	27	30
" Dividing, by contact measurements	27	26
" Dividing, by cord measurements	27	28
" Dividing, by correcting the accumulated errors	27	32
" Dividing, by mechanical correction of errors	27	24
" Pitch	17	4
" Root	17	6
Circles, Dividing of	27	23
" Locating the centers of	21	42
" Subdividing of	21	43
Circular pitch	17	5
" pitch, Proportions of gear-teeth for	17	8
" rack	18	28
Clamp bushings	31	10
" jigs	31	2
Clamping devices for bench work	20	8
" devices for jigs	31	12
Cleaning, Compressed air for	24	21
" work and castings	24	18
Clearance	17	7
" Angle of, for hob-forming tool	27	21
" Giving of, to dies	29	30
" of milling cutters	27	3
" of reamers	26	15
" Providing of, in grinding cutters	19	62
Clough duplex gear-cutter	18	10
Coal oil	24	37
Coining dies	29	7
" dies	30	33
" process	30	31
Cold chisels	20	16
Collapsing taps	25	33
Coloring	18G	23
Combination dies	29	7
" jigs	31	1
Compound dies	29	7
" dies	29	18
Compressed air for cleaning	24	21
Concrete floors for erecting	22	17
Cones, Rolling	17	33
Conical grinding	18G	42
" work, Grinding of	19	21

	Sec.	Page
Conjugate bevel gears	18	38
" tooth method of gear-cutting	18	3
" tooth method of gear cutting	18	22
Construction of tools	25	3
Corundum	18G	7
" Grading of	18G	9
" Properties of	18G	8
Cost of construction	24	28
" of pattern work	24	29
Counterbore, Solid	26	35
" Two-lipped flat	26	35
Counterbores	26	35
" Built-up	26	37
" Inserted cutter	26	38
" Inserted teeth	26	37
Cow bar	24	3
Crane	24	13
" Electric traveling	22	45
" Hand traveling	22	43
" Jib	22	41
" Power traveling	22	44
Cranes	22	41
Crank arm, Laying out of a	21	55
" shaft of an engine, Fitting the	23	31
" shaft, Squaring the	23	32
Cross-filing	20	38
Crosshead, Laying out of a	21	56
Cross-peen hammer	20	2
" rail of planer, Squaring of	23	16
Crown gear	18	28
Cupboards, Tool	24	58
Cup center	20	4
" wheel, Use of, in grinding	19	55
Curling	30	10
" dies	29	7
" dies	30	11
" dies, Tapering	30	12
Curves, Filing of	20	43
Cutter, Gang gear, Gould and Eberhardt	18	11
" gear, Clough duplex	18	10
" grinding	19	47
" grinding machine	19	48
" grinding, Position of guide finger during	19	51
" Setting the gear, for depth	18	8
Cutters, Cams for making formed	27	16
" Fly	27	9
Cutters for bevel gears, Selecting	18	14
" Gang, for gears	18	9
" Grinding cylindrical	19	50
" Grinding of clearance on	19	62
" Grinding of in place	19	63
" Formed	27	10
" formed, Sharpening of	19	61
" Lapping holes of milling	19	66
" Laying out of formed milling	27	14
" Methods of backing off	19	59
" milling, Backing off of formed	27	11
" milling, Grinding, in universal grinding machine	19	57
" milling, Grinding teeth of side	19	55
" Milling, with helical cutting edges	27	6
" Numbers of cutting edges for milling	27	1
" Standard for gear-cutting	18	5
" Tempering of milling	27	3
" with inserted teeth, Milling	27	5
Cutting a large spur gear	22	26
" bevel gears, with formed cutters	18	14
" dies	29	7
" dies	29	11
" edges for mills with inserted cutters, Number of	27	8
" edges for milling cutters, Helical	27	4
" edges for milling cutters, Helical	27	6
" edges for milling cutters, Number of	27	1
" edges for reamers, Helical	26	17
" edges for reamers, Number of	26	13
" edges, Number of, in dies	26	1
" edges of reamers, Spacing of	26	12
" racks	18	18

	Sec.	Page
Cutting speed for internal grinding	19	38
" worm-wheels with a formed cutter	18	36
Cycloid, Definition of	17	26
Cycloidal odontograph table, Grant's	17	27
" system of gear-teeth	17	18
" system of gear-teeth	17	26
" teeth, Laying out	17	26
Cylinder, Lining an engine, with the guides	23	30
" oil	24	36
Cylinders, Fitting on vertical engine	23	42
" Lagging of steam	24	54
" Lining locomotive	23	47
" locomotive, Placing of	23	55
" Pitch of	17	4
" Placing of, in locomotive erection	23	47
" Repairing leaky	24	33
Cylindrical grinding	18G	42
" iron blocking	22	4

D	Sec.	Page
Decimals, Reading of	25	6
Dedendum or root	17	6
Definite gauges	28	2
Depth of cut for gears	18	8
Derrick, Description of	24	13
" Dismantling a	24	17
" Erection of a	24	13
" mast	24	13
Design of milling cutters with inserted teeth	27	5
" of tools	25	2
Diagonal filing	20	41
Diameter, Pitch	17	5
" Pitch, of a worm	17	46
Diameters of gears for fixed center distances	17	17
Diametral pitch	17	5
Diamond, Black	19	68
" pointed chisel	20	18
" tools, Lapping of	19	68
Die, Adjustable pipe	21	32
" Combination cutting, drawing, and embossing	30	22
" Dip or shear of	29	13
" Gauge	29	13
" Gauge pin for	29	11
" Guide strip for	29	11
" holders	26	9
" Inserted-blade adjustable	26	8
Die, Laying out a simple	29	23
" Making a solid	26	2
" Making the	29	27
" Meaning of the term	29	1
" Plain forming	30	4
" Position of gauge pin for	29	23
" Simple forming	30	2
" sinking	20	25
" spring, Proportions of	26	7
" stock and round dies	21	29
" stock and square dies	21	28
Dies, Adjustable	26	6
" and die stock	21	28
" and punches	29	1
" Attachments used on	29	10
" Automatic	30	9
" Bending	30	6
" Classification of	29	6
" Coining	29	7
" Coining	30	33
" Combination	29	7
" Combination cutting and drawing	30	17
" Comparison of fastenings for	29	4
" Compound	29	7
" Compound	29	18
" Curling	29	7
" Cutting	29	7
" Cutting	29	11
" Degree of accuracy required in	29	9
" Design of	29	8
" Discharge of work from	30	26
" Drawing	29	7
" Economy of use of stock in	29	21
" Embossing	30	9
" Essential parts of plain	29	11
" Fastening for	29	4
" for can tops, Forming	30	4
" for curling	30	11
" for drop forging	30	34
" for forming	30	2
" for thread cutting	26	1
" for tube squirting	30	35
" Forming	29	7
" Forming, Difference in shape of upper and lower portions of	30	7
" Forms of	29	5
" Gang	29	8
" Gang	29	15
" Giving clearance to	29	30
" Hardening and tempering of	29	30

	Sec.	Page
Dies, Inserted-blade	26	4
" Laying out compound	29	27
" Laying out of	29	21
" Laying out progressive	29	24
" Method of fastening	29	3
" Non-adjustable	26	2
" Number of cutting edges of	26	1
" Operation of cutting drawing	30	18
" Plain	29	11
" Progressive	29	8
" Progressive	29	15
" Rake of cutting edges of	26	2
" Redrawing	30	28
" Seaming	30	10
" Self-centering	29	17
" Shear or dip of	29	32
" Special bulldozer	30	8
" Spring	26	6
" Spring drawing	30	15
" Spring drawing	30	18
" Tapering curling	30	12
" Temper required in	29	8
" Triple-action drawing	30	25
Differential chain block	22	40
" chain hoist	24	5
Dimensioning drawings	25	4
Dip of a die	29	13
" of dies	29	32
Disk grinders	18G	30
" grinding	18G	42
Dividing circles	27	23
Division of lines	27	34
" of lines, Mechanical	27	34
Double-action press	30	19
" belts	24	49
" cut files	20	30
" hitch	24	11
Dowel-pins, Use of, in engine erection	23	34
Draw-filing	20	40
" filing	20	44
Drawing	30	13
" dies	29	7
" dies	30	15
" dies, Triple-action	30	25
" Object of	30	14
" process	30	13
" Size of blanks for	30	26
" work with tapered or curved walls	30	21
Drawings, Dimensioning of	25	4
Drifting	21	9
Drill, Breast	21	9
" Crank-driven portable	21	8
Drill jigs	31	1
" Multiple-lip twist	26	27
" Scotch	21	8
Drilling crow	21	8
" ratchets	21	6
" ratchets, Use of	21	6
Driving fits	22	29
" fits, Allowance for	22	35
Drop forgings	30	34
Drying ovens used in galvanizing	24	22
Duplication system of gear-cutting	18	1

E	Sec.	Page
Earth floors for erecting	22	15
Electric traveling crane	22	45
Embossing	30	2
" dies	30	9
Emery	18G	9
" Grade of, for lapping	19	64
" wheel, Parts of	18G	11
" wheel, Sizing power of	19	27
" wheels, Bonds for	18G	11
" wheels, Bushing of	18G	13
" wheels, Classification of	18G	11
" wheels, Grading	18G	15
" wheels, Hand surfacing machines using	18G	28
" wheels, Manufacture of	18G	11
" wheels, Preparation of	18G	13
" wheels, Testing of	18G	17
" wheels, Truing of	18G	14
Engine, Appliances for erecting, on foundation	23	39
" Babbitting boxes of	24	66
" bed, Fitting of, to cylinder	23	28
" bed, Laying out of an	21	59
" bed, Lining of, with cylinder	23	29
" bed, Preparation of, for erection	23	27
" bed, Work necessary on vertical	23	42
" Dismantling a vertical	23	44
" Dismantling of	23	37
" Erecting a vertical, on foundation	23	46
" Erecting a vertical stationary	23	41
" erection	23	26
" erection, Equipment for	23	26

	Sec.	Page
Engine, Erection of a horizontal stationary	23	27
" Erection of, on foundation	23	38
" Fitting guides and cylinders of vertical	23	42
" Fitting the crankshaft of	23	31
" Fitting the flywheel of	23	34
" Fitting the reciprocating parts of	23	33
" Foundation bolt emplet for	23	37
" Gear-cutting	18	12
" lagging, Placing of	23	35
" Oiling devices for	23	34
" Oiling devices for vertical	23	44
" Painting and finishing of	23	37
" Placing on dead center	23	35
" Placing reciprocating parts on vertical	23	43
" Squaring the crankshaft of	23	32
" Use of dowel-pins in	23	34
" valves, Setting of	23	36
Epicycloid	17	26
Equaling file	20	28
" file	20	33
Erecting a gin pole	24	14
" a large rope wheel	22	27
" Earth floors for	22	15
" floor, Double-plank	22	15
" floor, Single plank	22	15
" floor, Wooden-block	22	17
" floors	22	14
" floors, Brick	22	17
" floors, Cast-iron plate	22	18
" floors, Concrete	22	17
" jacks, Heavy	22	10
" jacks, Simple	22	9
" large flywheel	22	25
" pit, Use of	22	25
" pits	22	19
" trucks	23	24
Erection, Comparison of two methods of locomotive	23	56
" Engine	23	26
" Locomotive	23	46
" Milling-machine	23	20
" of a derrick	24	13
" of lathes	23	4
Erection of lathes, Systems of	23	1
" of planers having legs	23	19
" Systems of planer	23	10
Errors, Accumulation of	25	10
" Reduction of accumulating	25	12
Expanding reamer	26	29
External grinding	18*G*	42
" grinding	19	16
" lapping	19	65
Eye splice	24	6

F	Sec.	Page
Face of tooth	17	7
" plate, Grinding work on a	19	24
" plate work in grinding	19	45
Feed, Automatic cross, for grinding machine	18*G*	52
Feeds used in grinding	19	8
Fellows' gear-shaper	18	23
File, Advantage of convex face of	20	35
" Back of	20	28
" Bastard	20	30
" Bellied	20	28
" Blunt	20	28
" Cant	20	33
" card	20	47
" Coarse	20	30
" Coarseness of cut of	20	30
" Dead smooth	20	30
" Equaling	20	28
" Equaling	20	33
" Flat	20	33
" Float	20	28
" Half-round	20	33
" Hand	20	33
" handle, Special	20	36
" handles, Wooden	20	35
" Holding the	20	37
" Hopped	20	28
" Middle cut	20	29
" Mill	20	33
" Pillar	20	33
" Pressure on	20	42
" Rat-tail	20	33
" Recut	20	29
" Rough	20	30
" Round	20	33
" Round-edged mill	20	33
" Safe-edged	20	29
" Second cut	20	30
" Single cut	20	30
" Size of	20	32
" Smooth	20	30

	Sec.	Page
File, Square-blunt	20	33
" Style of	20	32
" Superfine (or super) cut	20	29
" Taper	20	29
" Three-square	20	33
" Triangular	20	33
" Use of safe-edge	20	43
" Using the	20	40
Filed work, Finishing of	20	44
Files and filing	20	26
" British classification of	20	32
" Care of	20	46
" Double-cut	20	30
" Float	20	30
" Hand-cut	20	26
" Machine-cut	20	26
" Over-cut	20	30
" Pinning of	20	46
" Selection of	20	46
" Use of	20	26
Filing block	20	28
" broad surfaces	20	41
" Cross	20	38
" curves	20	43
" Diagonal	20	41
" Definitions and terms used in	20	27
" Draw	20	40
" Draw	20	44
" Effect of oil during	20	45
" Fitting keys by	20	48
" Height of work during	20	45
" into corners	20	43
" jigs	20	47
" jigs	31	1
" operations	20	34
" Position of body during	20	45
" Purpose of	20	34
" slots with curved ends	20	44
" stand	20	11
" templet for symmetrical work	29	28
Fillet of a gear-tooth	17	6
Filling and painting machine tools	24	28
Filter, Oil	24	44
Finishing filed work	20	44
Fits, Allowance for different classes of	22	35
" Driving	22	29
" force, Allowance for	22	36
" Press	22	29
" Press	22	32
" Shrink	22	29
" Shrink	22	36
" shrink, Allowance for	22	37
Fits, Taper-press	22	34
Flanges, Laying out bolt holes in	21	53
Flank	17	7
Flat chisel	20	16
" file	20	33
" scraper	21	2
" surfaces, Chipping large	20	22
Float file	20	28
" files	20	30
Floor, Double-plank erecting	22	15
" pits	22	19
" Single-plank erecting	22	15
" Wooden-block erecting	22	17
" work	20	1
Floors, brick, Erecting	22	17
" cast-iron plate, Erecting	22	18
" Concrete, for erecting	22	17
" Erecting	22	14
" for erecting, Earth	22	15
Flutes for taps, Forms of	25	21
" for taps, Number of	25	21
Fluting of reamers	26	14
Fly cutters	27	9
Flywheel, Assembling of large	22	25
" Fitting the	23	34
Follow rest for grinding	19	28
Force fit, Allowance for	22	35
Forgings, Drop	30	34
Formed cutter process of gear-cutting	18	2
" cutter process of gear-cutting	18	5
" cutters	27	10
" cutters, Backing off of	27	11
" cutters, Cams for making	27	16
" cutters, milling, Laying out of	27	14
" cutters, Sharpening of	19	61
" reamers	26	11
" reamers	26	33
Forming dies	29	7
" dies	30	2
" dies, Difference in shape of upper and lower portions of	30	7
" dies for can tops	30	4
" Meaning of the term	30	1
" Size of blanks for	30	26
" tool	27	17
Foundation, Appliances for erecting engine on	23	39
" bolt templet	22	14

	Sec.	Page
Foundation bolt templet for engine	23	37
" Erecting a vertical engine on a	23	46
" Erection of engine on	23	38
" Securing planer to	23	18
Foundations, Machine	22	13
Frames, locomotive, Placing of	23	50
" locomotive, Placing of	23	55
Friction, Lubricants for reducing	24	35

G

	Sec.	Page
Galvanizing	24	21
" bath, Use of lead in	24	26
" Precautions in	24	26
" Preparation of iron for	24	21
" Use of grease on bath during	24	24
Gang dies	29	8
" dies	29	15
" gear-cutter, Gould and Eberhardt	18	11
" gear-cutters	18	9
Gashing worm-wheels	18	37
Gauge, Aging of	28	5
" dies	29	13
" Gear-tooth depth	18	9
" Grinding a caliper	19	22
" Laying out a taper	28	24
" making	28	6
" Making an inserted bushing ring	28	10
" Making a plug	28	6
" Making a solid ring	28	9
" pin for die	29	11
" pin, Position of	29	23
" plate	29	13
" Seasoning of	28	5
" work, Limits of accuracy in	28	2
Gauges, Advantages of snap	28	15
" Classes of ring	28	8
" Classification of	28	1
" Definite and limit	28	2
" Distinguishing marks for limit	28	13
" for laying out keyseats	21	60
" Form of snap	28	15
" Hardened-steel	28	4
" Lap for finishing plug	28	7
Gauges, Laps for ring	28	11
" Limit of variation for limit	28	12
" Making large plug	28	8
" Making snap	28	17
" Master	28	1
" Materials used for	28	4
" Names of angular	28	20
" Needless accuracy in	28	3
" Plug	28	6
" Propositions of plug and ring	28	11
" Reference	28	1
" Ring	28	6
" Snap limit	28	16
" Soft steel	28	5
" Special	28	42
" Taper	28	1
" Taper	28	22
" Working	28	2
Gear attachment	18	12
" bevel, Bilgram cutter for	18	30
" Bevel, calculations	17	35
" bevel, Laying out blanks for	17	38
" blank	17	7
" calculations, Rules for	17	9
" Crown	18	28
" cutter, Automatic	18	13
" cutter, Clough duplex	18	10
" cutter, gang, Gould and Eberhardt	18	11
" cutter, Setting the, for depth	18	8
" cutter, Swasey	18	32
" cutters, Brown & Sharpe	18	6
" cutters, Pratt & Whitney	18	6
" Cutting a large spur	22	26
" cutting, Conjugate tooth method of	18	3
" cutting, Conjugate tooth method of	18	22
" cutting, Duplication system of	18	1
" cutting engine	18	12
" cutting, Formed cutter process of	18	2
" cutting, Formed cutter process of	18	5
" cutting, Generation system of	18	1
" cutting, Generation system of	18	22
" cutting, Hobbing process of	18	5

	Sec.	Page
Gear cutting, Methods and processes of	18	2
" cutting, Molding milling process of	18	4
" cutting, Molding milling process of	18	32
" cutting, Molding planing process of	18	3
" cutting, Molding planing process of	18	22
" cutting, Single-tooth molding planing process of	18	4
" cutting, Single-tooth molding planing process of	18	26
" cutting, Standard cutters for	18	5
" cutting, Systems of	18	1
" cutting, Templet grinding process of	18	21
" cutting, Templet planing process of	18	3
" cutting, Templet planing process of	18	20
" Definition of	17	3
" shaper, Fellows	18	23
" Spur	17	3
" teeth, Calculating the depth of	18	8
" teeth, Cycloidal	17	26
" teeth, Cycloidal or double-curved system of	17	18
" teeth, Diametral pitch of, Proportions of	17	9
" teeth, Devices for drawing	17	18
" teeth, Grant's cycloidal odontograph table for	17	27
" teeth, Involute or single-curved system of	17	18
" teeth, Laying out of	17	71
" teeth, Laying out of involute	17	20
" teeth, Octoidal	18	29
" teeth, Proportions of	17	8
" teeth, Robinson odontograph for	17	31
" teeth, Single-arc approximation for	17	21
" teeth, Walker odontograph chart for	17	32
" teeth, Willis odontograph for	17	30
" tooth caliper	18	17
Gear-tooth depth gauge	18	9
" tooth, Space of	17	6
" tooth, Thickness of	17	6
" wheel, Definition of	17	3
Gearing, Object of	17	1
" Worm	17	41
Gears, Bevel	17	33
" bevel, Cutting, with formed cutters	18	14
" bevel, Herring-bone	18	38
" bevel, Laying out of	17	35
" bevel, Molding milling of	18	36
" bevel, Selecting cutters for	18	14
" bevel, Setting milling machine to cut	18	15
" Conjugate bevel	18	38
" Depth of cut for	18	8
" Determining diameters of, for fixed center distances	17	15
" Gang cutters for	18	9
" internal, Cutting of	18	24
" Mesh of	17	3
" Miter	17	33
" Spur	17	1
" Standard pitches for	18	7
" Tooth curves for, in general use	17	18
" Velocity ratio of	17	14
Generation system of gear-cutting	18	1
" system of gear-cutting	18	22
Gin pole	24	13
" pole, Erection of a	24	14
Gisholt tool-grinding machine	18*G*	37
Glazing, Cause of, in grinding wheels	19	3
" of grinding wheels	18*G*	26
Gouge	20	18
Gould and Eberhardt gang gear-cutter	18	11
Grade of a grinding wheel	19	3
" of wheel for tool grinding	18*G*	38
Grading emery wheels	18*G*	15
" of grinding wheels	18*G*	25
Graduations on grinding machines	19	14
Granny's knot	24	13
Grant's cycloidal odontograph table	17	27
" involute odontograph table	17	22

	Sec.	Page
Grant's rule for rack teeth.....	17	25
Graphite.....	24	38
Grease.....	24	36
" for ball bearings.....	24	36
" for shafting.....	24	37
" Use of, on galvanizing bath.....	24	24
Greasy material, Disposition of	24	40
Grinders, Disk.....	18G	30
Grinding, Absorption of vibration, during.....	19	33
" Advantages of.....	19	1
" Allowance for, in reamers.....	6	17
" Applications of.....	18G	19
" Back rest for.....	19	28
" caliper gauges.....	19	22
" centers.....	19	24
" Chatter marks in....	19	9
" Chucks for use in .	19	44
" Classification of rest used in.....	19	27
" close to a shoulder..	19	22
" Comparison of, with turning.....	19	2
" Conical.....	18G	42
" conical work.....	19	21
" conical work.....	19	42
" Cutter and reamer..	19	47
" cutters in place.....	19	63
" cutters, Position of guide finger during.....	19	51
" Cutting speed for internal	19	38
" Cylindrical	18G	42
" cylindrical cutters..	19	50
" cylindrical work	19	18
" Definition of.....	18G	1
" Disk.....	18G	42
" ends of work.....	19	18
" External.....	18G	42
" External.....	19	16
" Feeds used in.....	19	8
" Fixed rest for.....	19	28
" fixture, Internal.....	19	40
" Flexible fixed rest for.....	19	29
" Follow rest for	19	28
" Hand.....	18G	27
" Influence of temperature on	19	11
" Internal...	18G	42
" Internal.....	19	37
" lathes.....	18G	41
" machine.....	18G	41

	Sec.	Page
Grinding machine, Automatic cross-feed for.....	18G	52
" machine, Driving work between centers on	19	16
" machine, Gisholt tool	18G	37
" machine, Plain.....	18G	48
" machine, Seller's tool	18G	35
" machine, Simple hand	18G	27
" machine, Surface....	19	46
" machine, Swinging-frame	18G	29
" Machine tool.....	18G	34
" machine, Universal	18G	43
" machine, Universal	18G	47
" machine, Universal, Using, as cutter grinder.....	19	57
" machine, Upright surface.....	18G	30
" machine, Wet, tool .	18G	33
" machines, Adjusting of..	19	14
" machines, Graduations on.....	19	14
" material.....	18G	1
" Methods of	19	16
" Methods of.....	19	42
" milling cutters... ...	27	3
" Noting the sparks during.....	19	13
" Object of.....	18G	19
" of bushings.....	31	12
" of work on face plate	19	45
" on a planer	19	45
" Poole method for, cylindrical work..	19	33
" Possibilities of.....	18G	20
" Pressure necessary for internal.....	19	37
" Prevention of heating during.....	19	11
" Radial.....	18G	42
" reamers	19	54
" reamers.....	26	18
" Rigid fixed rest for..	19	28
" Selection of wheels for external	19	5
" Selection of wheels for internal.....	19	5
" Selection of wheels for surface...	19	47
" Selection of wheels for tool	18G	28
" Set-wheel method of	19	26

	Sec.	Page
Grinding, Sizing power of wheel during	19	27
" solids of revolution	18G	42
" Special chucks for	19	25
" Special rests for	19	33
" Spring rest for	19	29
" Steadying of work during	19	27
" Surface	18G	42
" Surface	19	45
" Surface, Holding work during	19	47
" teeth of broaches	21	11
" teeth of side milling cutters	19	55
" Tool	19	47
" tools	18G	32
" tools, Speed of grindstone for	18G	5
" Universal back rest for	19	30
" Use of cup wheel in	19	55
" wheel, Combination	19	4
" wheel, Grade of	19	3
" wheel, Influence of hardness of work on	19	4
" wheel, Influence of vibration of work on	19	4
" wheel, Selection of	18G	25
" wheel, Selection of	19	3
" wheels	18G	7
" wheels, Cause of glazing in	19	3
" wheels, Directions for selection of	19	5
" wheels, Glazing of	18G	26
" wheels, Grading of	18G	25
" wheels, Shapes of	19	6
" wheels, Speeds of	18G	18
" wheels, Truing of	19	10
" work held in chuck	19	24
" work on a face plate	19	24
Grindstone, Action of water on a	18G	2
" Automatic truing device for	18G	3
" mountings	18G	3
" Speed of	18G	5
" Truing of by hand	18G	4
Grindstones	18G	2
" Artificial	18G	6
" Composition of	18G	2
" Origin of	18G	2
" Tool rests for	18G	3
Grooving chisel	20	18
" reamers	26	20
Guide bushings for jigs	31	6
" finger, Location of, on universal grinding machine	19	59
" finger, Mounting of, on universal grinding machine	19	57
" finger, Position of, in cutter grinding	19	51
" strip for die	29	11
Guides, Lining of, on locomotive	23	50

H	Sec.	Page
Hack saws, Hand	20	6
" saws, Power	20	6
Half-round file	20	33
Hammer, Ball-peen	20	2
" Cross-peen	20	2
" Holding, while chipping	20	19
" Pneumatic	20	24
" Straight-peen	20	2
Hand-cut files	20	26
" file	20	33
" grinding	18G	27
" reamer	21	15
" taps	25	23
Handles, File	20	35
Handy tackles	22	39
Hardening dies	29	30
" of taps	25	25
" the punch	29	32
Hardness, Scale of	18G	8
Heads of capscrews	24	73
" Setting of planer	23	19
Headstock spindle, Making taper holes in	23	7
Headstocks, Boring of lathe	23	3
" Machining of lathe	23	3
Heat insulation	24	54
" Lubricants for removing	24	41
Heater for making shrink fits	23	38
Heating, Prevention of, during grinding	19	11
Helical cutting edges for milling cutters	27	4
Herring-bone bevel gears	18	38
Hexagon, Laying out of	21	45
Hitch, Blackwall	24	11
" Catspaw	24	11
" Double	24	11
" Parbuckle	24	13

	Sec.	Page
Hitch, Timber	24	12
Hitches	24	11
Hob forming tool	27	21
" Number of slots in	27	22
Hobbed worm-wheel	17	42
Hobbing process of gear-cutting	18	5
" worm-wheels	18	37
Hobs	25	28
" Chaser	25	29
" Design of	25	28
" for worm-wheels	27	20
" Use of	25	28
Hoist, Differential chain	24	5
" Pneumatic	22	40
" Triplex	24	5
Hoists	22	38
" Chain	24	5
" Efficiency of	24	5
Holder, Blank	30	14
Hold-downs	29	10
Holes, Locating of, in jigs	31	26
Hollow mill for annular milling	26	43
" mills	26	39
" mills, Inserted-blade	26	40
Hook scraper	21	3
Hopped file	20	28
Horsepower	24	47
" and size of shafting	24	51
" of belts	24	48
Hot bearings, Curing of	24	38
Housings, Setting of planer	23	14
Hydraulic jacks	22	12
" press, General construction of	22	31
" press, Portable	22	31
Hydrofluoric acid for pickling	24	20
Hypocycloid	17	26

I	Sec.	Page
Indicator, Center	25	18
" Lathe	25	14
Indicators, Holder for	25	20
Inserted-blade adjustable die	26	8
" blade dies	26	4
" blade reamers	26	11
Inspecting ropes, slings, and lashings	24	4
Inspection of lathes	23	4
" of lathes	23	8
" of milling machines	23	24
Inspector's report on lathe	23	10
" report on milling machine	23	26
Internal gears, Cutting of	18	24
" grinding	18G	42
" grinding	19	37
" grinding, Cutting speed for	19	38
" grinding fixture	19	40
" grinding, Pressure necessary for	19	37
" lapping	19	64
Involute, Definition of	17	18
" odontograph table, Grant's	17	22
" system of gear-teeth	17	18
" teeth, Base circle for	17	19
" teeth, Laying out of	17	20
Iron, Blackening of	24	71
" blocking	22	3
" blocking, Cylindrical	22	4
" Bluing of	24	70
" Browning of	24	71
" Preparation of, for galvanizing	24	21

J	Sec.	Page
Jack, Laying out	22	9
" Sectional	22	9
" screws	22	10
Jacks	22	7
" Heavy erecting	22	10
" Hydraulic	22	12
" Lifting	22	10
" Simple erecting	22	9
" Simple leveling	22	7
" Stone	22	11
" Track	22	11
" Use of screw, in locating centers of work	21	42
Jaws, Vise	20	10
Jib crane	22	41
Jig, Babbitting	24	68
" design	31	16
" details	31	6
" making	31	16
" stops	31	3
" Tapping	21	20
Jigs, Babbitting	24	65
" Box	31	2
" Clamp	31	2
" Clamping devices for	31	12
" Classes of	31	1
" Combination	31	1
" Drill	31	1
" Essential parts of	31	2
" Filing	20	47
" Filing	31	1
" General requirements of	31	3

	Sec.	Page
Jigs, Locating holes in	31	26
" Locating holes in, by the button method	31	28
" Locating holes in, from a model	31	30
" Marking and recording of	31	33
" Reaming	31	1
" Size of guide hole in	31	11
" Stop-pins for	31	15
" Tapping	31	1
" Types of	31	2
" Uses of	31	1
Journal brasses, Babbitting	24	68

K	Sec.	Page
Kerosene	24	37
Kettle, Soda	24	18
Key, Sectional	24	60
Keys, Fitting, by filing	20	48
" Provision for withdrawing	20	49
" Round	20	50
" Taper	20	50
" Woodruff	20	50
Keyseats, Chipping of	20	22
" Gauges for laying out	21	60
Keyways, Broaching	21	12
Knife-edge straightedge	28	39
Knot, Bowline	24	13
" Granny's	24	13
" Square	24	13
Knots	24	11

L	Sec.	Page
Lagging, cutting, and fitting sheet iron	24	54
" Placing of engine	23	35
" steam cylinders and pipes	24	54
Laird of taps	25	22
Lap for finishing plug gauges	28	7
" Using a	19	64
Laps for ring gauges	28	11
Lapping	19	63
" a conical hole	19	65
" circular arcs	19	68
" diamond tools	19	68
" External	19	65
" Grade of emery for	19	64
" holes of milling cutters	19	66
" Internal	19	64
" odd shapes	19	66
" plane surfaces	19	67
" Purpose of	19	63
Lapping, Tools used in	19	63
" valve seats	19	66
Lashings, Inspection of	24	4
" Use of	24	4
Lathe, Backing-off attachment for	27	11
" beds, Machining of	23	2
" beds, Seasoning of	23	1
" beds, Testing of	23	2
" erection, Systems of	23	1
" headstocks, Machining of	23	3
" indicator	25	14
" Lining headstock and tail-stock spindles of	23	4
" Squaring carriage with spindle	23	7
" tail-stocks, Machining of	23	3
Lathes, Boring holes for headstock spindle	23	3
" Boring holes for tail-stock spindle	23	3
" Erection of	23	4
" Grinding	18G	41
" Inspection of	23	4
" Inspection of	23	8
" Making taper holes in headstock spindle	23	7
Laying out a crank-arm	21	55
" out a crosshead	21	56
" out a large journal cap	21	54
" out an engine bed	21	59
" out appliances, Special	21	52
" out bevel-gear blanks	17	38
" out bevel gears	17	35
" out bolt holes for pipe flanges	21	53
" out, Coatings used to make lines in	21	38
" out ends for small rods	21	61
" out jack	22	9
" out keyseats, Gauges for	21	60
" out of dies	29	21
" out plate for general work	21	49
" out plate for heavy work	21	47
" out plate for light work	21	45
" out plate, Revolving	21	50
" out tools	21	39
" out work	21	36
" out work, Divisions of	21	37
" out work, Examples of	21	53
" out work, Methods of	21	38
Lead, Black	24	38

	Sec.	Page
Lead, Use of, in galvanizing bath	24	26
Leather wheels	18G	24
Left-handed taps	25	33
Length of tooth	17	7
Leveling a planer bed	23	14
" jacks, Simple	22	7
Lifting jacks	22	10
Limit gauges	28	2
" gauges, Distinguishing marks for	28	13
" gauges, Limit of variation for	28	12
" gauges, Snap	28	16
Lines, Dividing, by the correction of accumulated errors	27	36
" Division of	27	34
" Mechanical division of	27	34
Lining an engine	23	29
Locomotive boiler, Placing of	23	56
" boiler, Testing the	23	52
" cylinders, Lining of	23	47
" cylinders, Placing of	23	55
" erection	23	46
" erection, Comparison of two methods of	23	56
" erection, Placing cylinders in	23	47
" frames, Placing of	23	50
" frames, Placing of	23	55
" Lining the guides of	23	50
" Placing the valve gear on	23	55
Long splice	24	6
Lubricant for cutting tools, A cheap	24	42
" Selecting a	24	35
" Turpentine as a	24	43
Lubricants	24	35
" Conditions under which no, are required	24	41
" for carrying away heat	24	41
" for cutting Babbitt metal	24	43
" for cutting steel	24	41
" for cutting wrought iron	24	41
" for drilling rawhide	24	43
Lubricants for reducing friction	24	35
" Preventing waste of	24	43
" Uses of	24	35
Lubrication of broaches	21	14
" Pipe system for	24	42

M	Sec.	Page
Machine, Adjusting of grinding	19	14
" Backing-off	27	11
" broaching	21	13
" cut files	20	26
" Cutter and reamer grinding	19	48
" foundations	22	13
" Gisholt tool-grinding	18G	37
" grinding	18G	41
" grinding, Automatic cross-feed for	18G	52
" Plain grinding	18G	43
" Seller's tool-grinding	18G	35
" Simple hand-grinding	18G	27
" Surface grinding	19	46
" Swinging-frame grinding	18G	29
" taps	25	26
" tool grinding	18G	34
" tools, Painting of	24	28
" Universal grinding	18G	43
" Universal grinding	18G	47
" Wet, tool grinding	18G	33
Machines, Hand-surfacing	18G	28
" Inspection of milling	23	24
Machining lathe beds	23	2
" of lathe tail-stocks	23	3
Mandrels for babbitting	24	64
Marking material used in scraping	21	5
Marlinspike	24	7
Mast, Derrick	24	13
Master gauges	28	1
Material, Influence of hardness of, on grinding wheel	19	4
Materials, Abrasive	18G	7
" used for gauges	28	4
Matrix or die	29	1
Measurements, Accuracy attainable in	28	3
" Approximate	25	8
" Classification of	25	8
" Precise	25	9
Mechanical division of lines	27	34

	Sec.	Page
Mesh as applied to gearing	17	7
" of gears	17	8
Metal, Babbitt, Composition of	24	61
" Melting of Babbitt	24	62
Micrometer caliper, Accuracy obtainable with	28	8
" Special form of, for dividing lines	27	36
Middle cut file	20	29
Mill file	20	33
Milling bevel gears, Molding	18	36
" cutter, Tempering of	27	3
" cutters	27	1
" cutters, Backing-off of formed	27	11
" cutters, Clearance of	27	3
" cutters, Grinding, in universal grinding machine	19	57
" cutters, Grinding of	27	3
" cutters, Grinding teeth of side	19	55
" cutters, Helical cutting edges for	27	4
" cutters, Lapping holes in	19	66
" cutters, Left-handed	27	4
" cutters, Methods of backing off	19	59
" cutters, Nicked teeth for	27	4
" cutters, Number of cutting edges for	27	1
" cutters, Right-handed	27	4
" cutters, Spiral	27	4
" cutters with helical cutting edges	27	6
" cutters with inserted teeth	27	5
" Hollow mill for annular	26	43
" machine erection	23	20
" machine, Setting, to cut bevel gears	18	15
" machines, Inspection of	23	24
" process of gear-cutting, Molding	18	32
" racks	18	19
Mills, Inserted-blade hollow	26	40
" Solid hollow	26	39
" with inserted cutters, Number of cutting edges of	27	8
Miter gears	17	33
Model for locating holes in a jig	31	31
Molding milling bevel gears	18	36
" milling process of gear-cutting	18	4
" milling process of gear-cutting	18	32
" planing process of gear-cutting	18	3
" planing process of gear-cutting	18	23
" planing process of gear-cutting, Single-tooth	18	4
" planing process, Single-tooth	18	26
" process of gear-cutting	18	22

N

	Sec.	Page
Naphtha	24	38
Nicked teeth for milling cutters	27	4

O

	Sec.	Page
Object of gearing	17	1
Octoidal teeth for gears	18	29
Odontograph for gear-teeth	17	18
" Robinson	17	31
" table, Grant's cycloidal	17	28
" table, Grant's involute	17	22
" tables	17	18
" Willis	17	30
Oil channels	24	39
" Coal	24	37
" Cylinder	24	36
" Effect of, during filing	20	45
" filter	24	44
" for general shop use	24	36
" holes	24	39
" Mineral sperm	24	37
" Paraffin	24	37
" separator	24	43
Oiling devices for vertical engine	23	44
Oils, Objection to animal	24	36
" Thinning of	24	37
" Volatile	24	38
Oilstones, Artificial	18G	7
" Composition of	18G	6
" Kinds and qualities of	18G	6
Old man, for use with ratchet	21	8

	Sec.	Page
Originating angles	28	26
" tapers	28	26
Overcut files	20	30
P	*Sec.*	*Page*
Painting and finishing engines	23	37
" machine tools	24	28
Paraffin oil	24	37
Parallel blocks	22	8
" blocks, Adjustable	22	5
Parbuckle	24	13
Patching chipped castings	24	32
Patternwork, Cost of	24	29
Petroleum, Refined	24	37
Pickle bed	24	20
Pickling solutions	24	19
Pillar file	20	33
Pinning of files	20	46
Pinch bars	24	2
Pinion	17	8
Pipe cutter	21	30
" die, Adjustable	21	32
" flanges, Laying out bolt holes in	21	53
" stock	21	31
" Threads, Tapping of	21	21
" Threading of	21	31
" tongs	21	33
" tongs, Chain	21	34
" vise	20	9
" vises	21	32
" wrench, Use of rope as	21	35
" wrenches	21	33
Pipes, Lagging of steam	24	54
Pit, Use of erecting	22	25
Pitch circle	17	4
" circle for bevel gears	17	34
" Circular	17	5
" Circular, Proportions of gear-teeth for	17	8
" cones for bevel gears	17	34
" cylinders	17	4
" diameter	17	5
" diameter of a worm	17	46
" Diametral	17	5
" point	17	7
" Rule to change circular to diametral	17	9
" Rule to change diametral to circular	17	10
Pits, Floor	22	19
Plain dies	29	11
" grinding machines	18*G*	43
Planchet	30	33
Plane, Scraping	28	41
" surfaces, Lapping of	19	67
Planer bed, Leveling a	23	14
" beds, Supporting of	23	12
" castings, Precautions in regard to	23	12
" Erection of, on foundation	23	18
" erection, Systems of	23	10
" Grinding on a	19	45
" heads, Setting of	23	19
" housings, Setting of	23	14
" Preparation of, for shipment	23	17
" Securing of, to foundation	23	18
" Squaring of cross-rail of	23	16
" table, Placing of	23	15
Planers, Classes of	23	11
" having legs, Erection of	23	19
Plate for laying out general work	21	49
" for laying out heavy work	21	47
" Gauge	29	13
" Laying out, for light work	21	45
" revolving, Laying out	21	50
" surface, Use of, in scraping	21	5
Plates, Surface	21	40
Plug gauge, Making a	28	6
" gauges	28	6
" gauges, Lap for finishing	28	7
" gauges, Making large	28	8
" gauges, Proportions of	28	11
Plumbago	24	38
Plunger of a double-action press	30	19
" or punch	29	1
Pneumatic hammer	20	24
" hoist	22	40
Pole, Gin	24	13
Polishing and buffing, Distinction between	18*G*	22
" Material used for	18*G*	23
" Object of	18*G*	20
" wheels and belts	18*G*	20
Poole method of grinding cylindrical work	19	33
Portable work benches	20	14
Post work bench	20	16
Power, Transmission	24	45
" transmitted by cold-rolled head-shafts	24	51

	Sec.	Page
Power transmitted by cold-rolled line shafting	24	53
" transmitted by turned-iron head-shafts	24	50
" transmitted by turned-iron line shafting	24	52
" traveling crane	22	44
Pratt & Whitney gear-cutters	18	6
Press, Double-action	30	19
" fits	22	29
" fits	22	32
" fits, Taper	22	34
" General construction of hydraulic	22	31
" Portable hydraulic	22	31
" Single-action	30	19
Presses, Object of setting, on an angle	30	26
Prick punch	20	2
Profiling templet	29	28
Progressive dies	29	8
" dies	29	15
Punch, Bolster of a	29	3
" Definition of	29	1
" Fitting of the	29	31
" Hardening and tempering of	29	32
" Prick	20	2
" Self-centering	29	12
" Spiral	29	12
Punching	29	12

R	Sec.	Page
Rack	17	8
" Circular	18	28
" cutting	18	18
" Determining thickness by adjustable parallel	22	6
" teeth, Grant's rule for	17	25
Racks, Tool	24	59
Radial grinding	18G	42
Rag wheel	18G	24
Ram	24	60
" of a punching machine	29	2
Ratchet, Drilling crow for	21	8
" drilling, Use of	21	6
" Old man for use with	21	8
" Special	21	8
" wrenches	21	26
Ratchets, Drilling	21	6
Ratio, Velocity	17	1
Rawhide, Lubricants for cutting	24	43
Reading decimals	25	6
Reamer, Expanding	26	29
" grinding	19	47
Reamer grinding	19	54
" grinding machine	19	48
" Hand	21	15
" Step	21	15
" Taper	21	16
Reamers, Adjustable	26	11
" Adjustable	26	28
" Allowance for grinding	26	17
" Chattering of	26	12
" Chucking	26	27
" Classification of	26	11
" Clearance of	26	15
" Enlarging worn solid	26	25
" Fluting of	26	14
" Formed	26	11
" Formed	26	33
" Four-square	26	33
" Grinding of	26	18
" Grooving of	26	20
" Gunsmith	26	33
" Helical cutting edges for	26	17
" Inserted-blade	26	11
" Methods of backing off	19	59
" Number of cutting edges for	26	13
" Rose	26	26
" Shell	26	25
" Solid	26	11
" Stepped	26	23
" Straight	26	11
" Taper	26	11
" Taper	26	23
" Temper of	26	22
" Use of	26	11
Reaming, Advantage of vertical	21	17
" Example of vertical	21	18
" holes in line	21	18
" jigs	31	1
" Object of hand	21	15
" stand	20	11
Reciprocating parts of an engine, Fitting the	23	33
" parts, Placing of, on vertical engine	23	43
Recut file	20	29
Redrawing	30	14
" dies	30	28
" Reverse	30	30
Reeding	30	32
Reference gauges	28	1

	Sec.	Page
Releasing die holders	26	9
" tap holders	25	86
Relief of taps	25	26
Rest, Back, for grinding	19	28
" Fixed, for grinding	19	28
" Flexible fixed, for grinding	19	29
" Follow, for grinding	19	28
" Rigid, fixed, for grinding	19	28
" Spring, for grinding	19	29
" Universal back, for grinding	19	30
Rests, Special, for grinding	19	33
" used in grinding, Classification of	19	27
Reverse redrawing	30	30
Revolving laying-out plate	21	50
Rigging	24	1
Ring gauge, Making an inserted-bushing	28	10
" gauges	28	6
" gauges, Classes of	28	8
" gauges, Laps for	28	11
" gauges, Proportions of	28	11
Robinson odontograph	17	31
Rods, Laying out ends for small	21	61
Root circle	17	6
" diameter	17	5
" or dedendum	17	6
Rope wheel, Assembling a large	22	27
Ropes, Inspection of	24	4
" Materials used for	24	6
Rose reamers	26	26
Roughing, Chucking reamers for	26	27
Round file	20	33
" files, Use of	20	43
" keys	20	50
Rubber, Cutting soft	24	70
" Working vulcanized	24	70
Running fits, Allowance for	22	35

S	Sec.	Page
Saddle, Squaring lathe, with spindle	23	7
Safe-edged file	20	29
Sal ammoniac, Use of, in galvanizing	24	24
Saws, Hand hack	20	6
" Power hack	20	6
Scale of hardness	18*G*	8
Scotch drill	21	8
Scrap heap	24	32
" or wad	29	12
Scraper, Bent or hook	21	3
" Flat	21	2
Holding of	21	4
Three-cornered	21	2
Scrapers, Forms of	21	2
" Use of	21	1
Scraping	20	29
" a plane surface	21	5
" Marking material used in	21	5
" plane	28	41
" Use of surface plate in	21	5
Screw heads	24	72
" vise	20	8
Screws, Putting in wood	24	69
Scriber	20	4
Seaming dies	30	10
Seasoning lathe beds	23	1
Selection of a grinding wheel	19	3
Self-centering dies	29	17
Seller's tool-grinding machine	18*G*	35
Separator, Oil	24	43
Set wheel method of grinding	19	26
Setting engine valves	23	36
" planer heads	23	19
Shafting	24	50
" Grease for	24	37
" Horsepower and size of	24	51
" Power transmitted by cold-rolled iron line	24	53
" Power transmitted by turned-iron line	24	52
" Power transmitted by turned-iron head	24	50
Shaper, Fellows gear	18	23
Sharpening formed cutters	19	61
Shear of a die	29	13
" or dip of dies	29	32
Shell reamers	26	25
Shellac wheels	18*G*	12
Short splice	24	6
Shrink fits	22	29
" fits	22	36
" fits, Allowance for	22	37
" fits, Special heater for	22	38
Side chisel	20	18
Silicate wheels	18*G*	12
Single-action press	30	19
" cut file	20	30
Sizing power of an emery wheel	19	27
Slings, Inspection of	24	4
" Use of	24	3
Snap gauges, Advantages of	28	15

	Sec.	Page
Snap gauges, Form of	28	15
" gauges, Making of	28	17
" limit gauges	28	16
Socket wrenches	21	25
Soda kettle	24	18
Solutions, Pickling	24	19
Sparks, Noting of, during grinding	19	13
Special gauges	28	42
Speed, Belt	24	48
" Cutting, for internal grinding	19	38
" of grinding wheel and work	19	8
Spindle, Making taper holes in headstock	23	7
Spindles, Boring for lathe headstock and tail-stock	23	3
" Lining headstock and tail-stock of lathe	23	4
Spiral bevel gears	18	38
" milling cutters	27	4
Splice, Eye	24	6
" Long	24	6
" Making a long	24	9
" Making a short	24	7
" Making an eye	24	10
" Short	24	6
Splices	24	6
Splicing instruments	24	7
" tools	24	7
Spotting of work in grinding	19	29
Spring die	26	6
" rest for grinding	19	29
Spur gear	17	3
" gear calculations, Rules for	17	9
" gears	17	1
Square knot	24	13
" Laying out of	21	45
" Making a try	28	31
" threaded taps	25	33
Squares, Testing try	28	33
Squaring tapped holes	21	19
Stand, Filing	20	11
" Reaming	20	11
Staybolt tap, Wrench for	21	22
Steady rests, Benefits from use of	19	27
Steam cylinders, Lagging of	24	54
" pipes, Lagging of	24	54
Steel, Blackening of	24	71
" Bluing of	24	70
" Browning of	24	71
Steel, Lubricants for cutting	24	41
" Seasoning of	28	5
Step reamer	21	15
Stock, Amount of, left between holes by punches	29	23
" Economy in use of, in dies	29	21
Stone jacks	22	11
Stop-pins for jigs	31	15
Stops for jigs	31	3
Straight peen hammer	20	2
" reamers	26	11
Straightedge, Knife-edge	28	39
" Number necessary to originate one	28	37
" Originating a	28	37
Straightedges	21	40
" Finishing the testing edge of	28	40
" Forms of	28	38
" Hardening of	28	40
" Long	21	41
Straightening taps	25	25
Strip, Chipping	20	24
Strippers	29	10
Stud-bolt wrench	21	27
Sulphuric acid for pickling	24	19
Surface grinding	18G	42
" grinding	19	45
" grinding machine	19	46
" plate, Use of, in scraping	21	5
" plates	21	40
" Scraping a plane	21	5
Surfaces, Chipping a large flat	20	23
" Lapping of plane	19	67
Surfacing machines, Hand	18G	28
Swasey gear-cutter	18	32
Swivel vise	20	9

T	Sec.	Page
Table, Placing of planer	23	15
Tackle block	22	39
Tackles, Handy	22	39
Tail-stocks, Boring of lathe	23	3
" stocks, Machining of lathe	23	3
Tanite wheels	18G	13
Tap holders, Releasing	25	36
" Making a hand	25	23
" wrench for staybolt	21	22
Taper, Different definitions of	28	22
" file	20	29
" gauge, Laying out of	28	24
" gauges	28	1

	Sec.	Page
Taper gauges	28	22
" keys	20	50
" press fits	22	34
" reamers	26	11
" reamers	26	23
" reaming	21	16
" taps	25	26
" taps, Errors in	25	27
Tapers, Originating	28	26
Tapped hole, Squaring of	21	19
Tapping	21	18
" jig	21	20
" jigs	31	1
" pipe threads	21	21
" Production of smooth threads in	21	20
Taps, Adjustable	25	30
" Collapsing	25	33
" Cutting thread of, with die	25	24
" Design and construction of	25	21
" Design of collapsing	25	34
" Errors in taper	25	27
" for brass, Square-thread	25	38
" for square threads	25	38
" Form of flutes for	25	21
" Hand	25	28
" Hardening of	25	25
" Land of	25	22
" Left-handed	25	33
" Location of cutting faces of	25	22
" Machine	25	26
" Making of collapsing	25	35
" Multiple-threaded	25	33
" Number of, necessary in a set	21	21
" Number of flutes for	25	21
" Number of, required in special cases	25	38
" Object of fluting	25	21
" Relief of	25	26
" Square-threaded	25	33
" Straightening of	25	25
" Taper	25	26
Teeth, Convergence of bevel gear	17	35
" Depth of cut for gear	18	8
" for milling cutters, Nicked	27	4
" gear, Depth gauge for	18	9
" gear, Devices for drawing	17	18
" gear, Laying out of	17	17
Teeth gear, Proportions of, for diametral pitch	17	9
" gear, Space of	17	6
" gear, Thickness of	17	6
" involute, Base circle for	17	19
" Laying out of cycloidal	17	26
" Length of	17	7
" Octoidal gear	18	29
" of broaches, Angle of	21	14
" of gears, Calculating the depth of	18	8
" of worm-wheel, Depth of	17	45
" Proportions of gear	17	8
" rack, Grant's rule for	17	25
" Width of	17	7
Temper of reamers	26	22
" required in dies	29	8
Temperature, Influence of, on grinding	19	11
Tempering dies	29	30
" of milling cutters	27	3
" the punch	29	32
Templet for symmetrical work, Filing	29	28
" Foundation bolt	22	14
" Foundation bolt for engine	28	37
" grinding process of gear-cutting	18	21
" planing process of gear-cutting	18	3
" planing process of gear-cutting	18	20
Testing emery wheels	18*G*	17
" lathe beds	28	2
Thread cutting, Dies for	26	1
" cutting, Inside	21	18
" Effect of hardening on pitch of	25	25
" worm, Form of	17	48
Threading pipe	21	31
Threads, Production of smooth, in tapping	21	20
Three-cornered scraper	21	2
Throat diameter of a worm-wheel	17	45
Timber hitch	24	19
Time element in work	24	30
Tinning	24	26
" by dipping the work into molten tin	24	26
" by the cold process	24	27
Tongs, Pipe	21	33
Tool cupboards	24	58
" Forming	27	17

	Sec.	Page
Tool grinding	18G	32
" grinding	19	47
" grinding by hand	18G	32
" grinding machine	18G	34
" grinding machine, Gisholt	18G	37
" grinding machine, Seller's	18G	35
" grinding machine, Wet	18G	33
" grinding, Selection of wheels for	18G	38
" Hob-forming	27	21
" racks	24	59
" rests for grindstones	18G	3
Toolmaker, Work of the	25	7
Toolmaking	25	1
" Limitations of	25	13
" Special tools used in	25	14
Tools, Cheap lubricant for cutting	24	42
" Construction of	25	3
" Design of	25	2
" for splicing	24	7
" Keeping machine-shop	24	57
" Lapping diamond	19	68
" Laying out	21	39
" Painting machine	24	28
" Roller, for expanding metal linings	24	64
" Speed of grindstone in grinding	18G	5
" used in toolmaking, Special	25	14
Tooth, Breadth of	17	7
" curves for bevel gears, Laying out	17	39
" curves in general use	17	18
" Face of	17	7
" Flank of	17	7
Tote boxes	24	56
Track jacks	22	11
Tram for engine	23	35
Transmission of power	24	45
Traveling crane, Electric	22	45
" crane, Hand	22	43
" crane, Power	22	44
Trestles	22	2
Triple-action drawing die	30	25
Triplex hoist	24	5
Trolley system for handling work	22	42
Trucks, Erecting	23	24
Truing emery wheels	18G	14
" grinding wheels	19	10
Try square, Making a	28	31
" squares	28	31
" squares, Testing of	28	33
Tube squirting	30	35
Turpentine	24	38
" as a lubricant	24	43
Twist drill, Multiple-lip	26	27

U	Sec.	Page
Universal back rest for grinding	19	30
" grinding machine	18G	43
" grinding machine	18G	47

V	Sec.	Page
Valve gear, Placing, on locomotive	23	55
" seats, Lapping of	19	66
" setting	23	36
Velocity ratio	17	1
" ratio, Constant, in gearing	17	7
" ratio of gears	17	14
" ratio of worm-wheels	17	44
Vertical engine, Dismantling a	23	44
" engine, Oiling devices for	23	44
" reaming, Advantage of	21	17
" reaming, Example of	21	18
" stationary engine, Erecting a	23	41
Vibration, Absorption of, during grinding	19	33
" of work, Influence of, on grinding wheel	19	4
Vise, Cam and lever	20	8
" jaws	20	10
" jaws, Protection of work from	20	10
" Pipe	20	9
" Rapid-motion	20	8
" Screw	20	8
" Swivel	20	9
" work, Tools used in	20	2
Vises, Pipe	21	32
" Special forms of	20	11
Vitrified emery wheels	18G	12
Volatile oils	24	38
Vulcanite wheels	18G	12

W	Sec.	Page
Wad	29	12
Walker odontograph chart	17	32
Waste, Disposition of greasy	24	40
" Use of	24	40
Water, Action of, on a grindstone	18G	2